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Contract NAS 1-12494

CIVIL HELICOPTER NOISE ASSESSMENT STUDY  
BOEING VERTOL MODEL 347

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ASSESSMENT STUDY BOEING-VERTOL MODEL 347  
Final Report (Boeing Vertol Co.,  
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By Ernest G. Hinterkeuser  
And Harry Sternfeld, Jr.

Prepared by

BOEING VERTOL COMPANY  
Philadelphia, Pa.

For

Langley Research Center  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

May 3, 1974

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TABLE OF CONTENTS

	Page
SUMMARY .....	1
INTRODUCTION .....	2
NOISE CRITERIA FORECASTS .....	4
Certification Criteria .....	4
Community Noise Criteria .....	16
AIRCRAFT NOISE REDUCTION PROGRAM .....	26
Aircraft Noise Signature .....	26
Component Noise Reduction Requirements .....	39
Component Noise Reduction Approaches .....	45
Technology Status Assessment .....	71
CONCLUSIONS .....	73
APPENDIX A: ROTOR NOISE ANNOYANCE .....	75
REFERENCES .....	81
BIBLIOGRAPHY .....	82

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TABLES

<u>Table</u>		<u>Page</u>
I	FACTORS INCLUDED IN VARIOUS COMMUNITY NOISE RATING METHODS . . . . .	18
II	HELICOPTER NOISE REDUCTION APPROACHES - TECHNOLOGY STATUS ASSESSMENT . . . . .	72

ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1. Boeing Model 347 Helicopter . . . . .	3
2. Three Point Noise Measurement Locations Subsonic Jet Airplanes . . . . .	6
3. Possible Certification Noise Measurement Locations for Helicopters . . . . .	8
4. Effect of Time Duration Correction on Subjective Response . . . . .	9
5. Correlation Between Perceived Noise Level and "A" - Weighted Sound Pressure Level for Various Helicopter Take-Offs and Landings . . . . .	11
6. Comparison of External Noise of Boeing Helicopters . . . . .	13
7. Aircraft Noise Criteria from Reference 3 . . . . .	14
8. Plan for Future Certification Noise Limits . . . . .	15
9. Comparison of Various Noise Exposure Indices . . . . .	19
10. Example of Application of Community Noise Criteria . . . . .	22
11. Daytime Outdoor Noise Levels Found in 18 Locations Ranging Between the Wilderness and the Downtown City . . . . .	24
12. Comparison with Other Limits . . . . .	25
13. Comparison with Possible Certification Limits at 500 Feet . . . . .	27
14. Model 347 Helicopter Approach and Departure Flight Trajectories . . . . .	28
15. Model 347 Effective Perceived Noise Level Con- tours (EPNL) - Vertical to 120' - 10 Degree Climb	29

<u>Figure</u>	<u>Page</u>
16. Model 347 Effective Perceived Noise Level Contours (EPNL) - Vertical to 750' - 10 Degree Climb . . . . .	30
17. Model 347 Effective Perceived Noise Level Contours (EPNL) - Vertical to 1500' - 10 Degree Climb . . . . .	31
18. Model 347 Effective Perceived Noise Level Contours (EPNL) - 10 Degree Approach . . . . .	32
19. Model 347 Effective Perceived Noise Level Contours (EPNL) - 9 Degree Approach to 500' - Vertical Landing . . . . .	33
20. Model 347 Effective Perceived Noise Level Contours (EPNL) - 25 Degree Approach . . . . .	34
21. Comparison of Model 347 Helicopter Perceived and Effective Perceived Noise Levels in Takeoff and Landing . . . . .	35
22. Perceived Noise Weighting Factors (Noys by Octave) - 10 Degree Takeoff . . . . .	37
23. Perceived Noise Weighting Factors (Noys by Octave) - 10 Degree Landings . . . . .	38
24. Detailed Noise Distribution for Most Critical Certification Point - Unmodified Aircraft . . . . .	40
25. Detailed Noise Distribution for Most Critical Certification Point - Modified Rotor Blades . . . . .	41
26. Detailed Noise Distribution for Most Critical Certification Point - Modified Rotor Blades and Engines . . . . .	42
27. Modified Model 347 Effective Perceived Noise Level Contours (EPNL) - Vertical to 120' - 10 Degree Climb . . . . .	43

<u>Figure</u>	<u>Page</u>
28. Modified Model 347 Effective Perceived Noise Level Contours (EPNL) - 10 Degree Approach . . .	44
29. Blade "Bang" Signature . . . . .	46
30. Effect of Blade-Vortex Spacing on Rotor Noise - UHM Model Data . . . . .	47
31. Effect of Rotor-Vortex Interaction on Acoustic Waveforms . . . . .	48
32. Blade Tip Concepts . . . . .	50
33. Effect of Blade-Vortex Separation on Impulsive Rotor Noise . . . . .	51
34. Single Rotor Hover Impulsive Noise Criteria . .	53
35. Lift Divergence Boundaries for Several Airfoil Sections . . . . .	54
36. Model 347 Flyby Noise - 170 Knot True Airspeed .	55
37. Single Rotor Bang Cruise Noise Limits . . . . .	56
38. Thin Tip - Concept . . . . .	57
39. Thin Tip - Noise Test Results . . . . .	58
40. Thin Tip - Psychoacoustic Test Results . . . . .	59
41. Improvement of Bang Envelope by Thin Tip . . . .	61
42. Double Swept Tip Concept . . . . .	62
43. Double Swept Tip - Objective Noise Evaluation .	63
44. Double Swept Tip - Subjective Noise Evaluation .	64
45. Effect of Tip Speed on Hover Noise . . . . .	65
46. Noise Reduction by Rotor Harmonic Control . . .	68

<u>Figure</u>		<u>Page</u>
47.	Effect of Blade Torsional Rigidity on Noise . .	69
A1.	Presentation of Synthesized Rotor Noise to Test Subjects . . . . .	78
A2.	Relative Levels of Three Types of Rotor Sounds Judged Equally Annoying to a Broadband Noise . .	79

CIVIL HELICOPTER NOISE ASSESSMENT  
BOEING-VERTOL MODEL 347

By Ernest G. Hinterkeuser  
And Harry Sternfeld, Jr.  
The Boeing Vertol Company

SUMMARY

A study was conducted to forecast the noise restrictions which may be imposed on civil transport helicopters in the 1975-1985 time period. Certification and community acceptance criteria were predicted.

A 50 passenger tandem rotor helicopter based on the Boeing-Vertol Model 347 was studied to determine the noise reductions required, and the means of achieving them.

Some of the important study recommendations are:

1. Certification limits should be equivalent to 95 EPNdB at data points located at 500 feet to each side of the touchdown/takeoff point, and 1000 feet from this point directly under the approach and departure flight path.
2. Community acceptance should be measured as Equivalent Noise Level ( $L_{eq}$ ), based on dBA, with separate limits for day and night operations.
3. In order to comply with the above guidelines, the Model 347 helicopter will require studies and tests leading to the following modifications:
  - o New blade tips to delay onset of drag divergence in cruise;
  - o Rotor blade geometry modification to reduce rotational and broadband noise.
  - o Increased fuselage length to eliminate rotor aerodynamic overlap.
  - o Powerplant silencing.

## INTRODUCTION

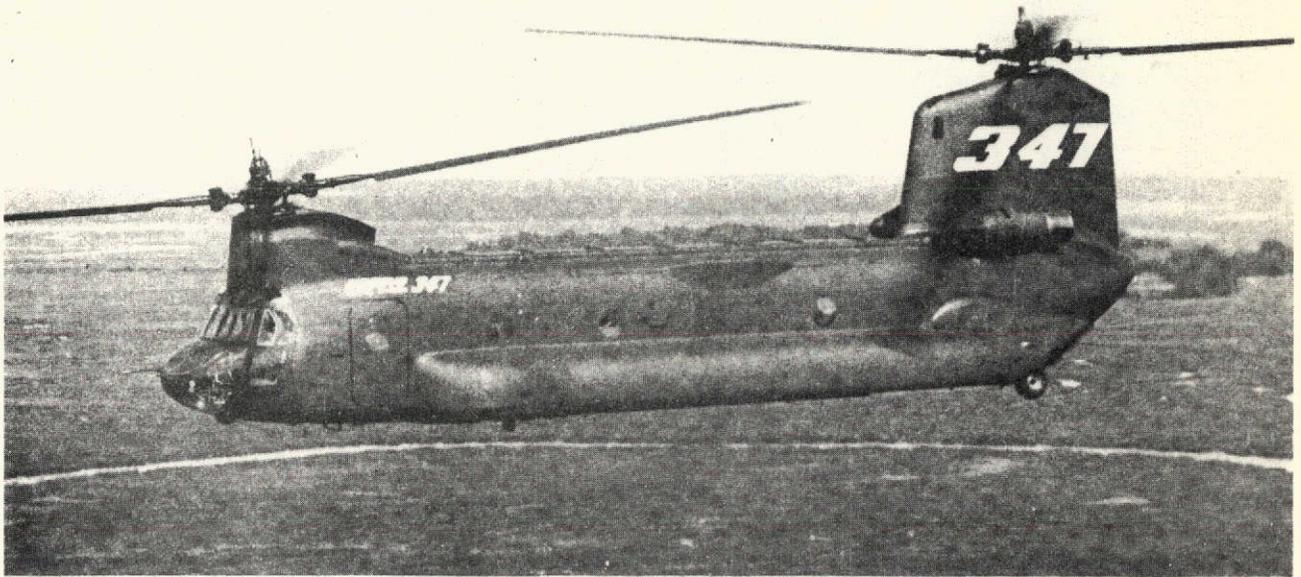
The helicopter's uniqueness lies in its ability to hover, rise, and descend along a steep flight path. Helicopters used for civil transportation therefore, will be utilized where available property areas are limited. The close proximity of public involvement is also apparent.

In view of the operation just described, it is evident that exterior noise radiated from the helicopter, and its effect on the neighboring population, may become a parameter which determines if civil helicopter operations, on a scale large enough to impact public transportation problems, can be conducted.

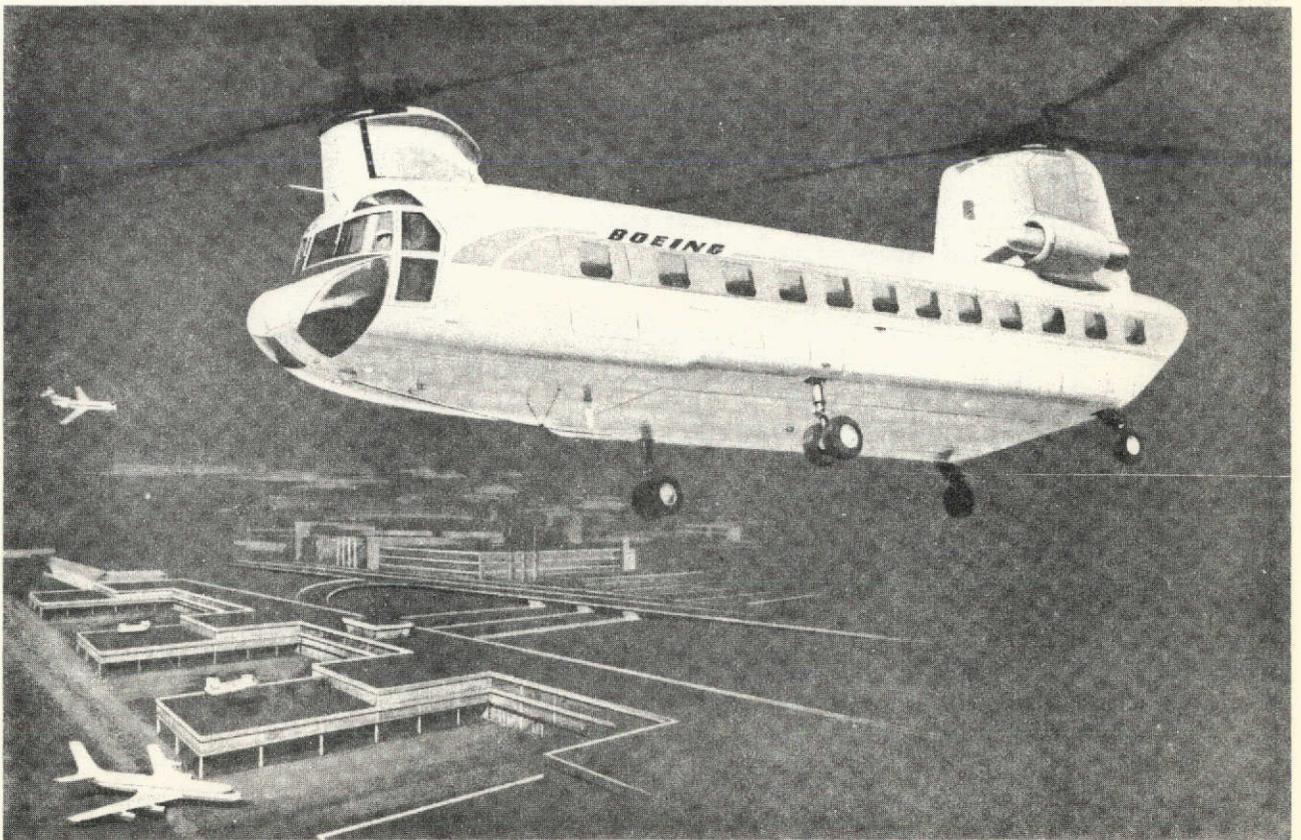
Although considerable attention has been directed at the noise generated by jet airplanes, little corresponding effort has been generated towards investigating the problems of helicopter noise criteria, regulations, and the impact of noise limitations on design and operation. On December 28, 1973, the FAA announced an Advanced Notice of Proposed Rule Making (ANPRM), entitled "Noise Standards, Short Haul Aircraft". This ANPRM requests public comment on many aspects of VTOL, STOL, and RTOL noise certification, but does not define a specifically intended regulation.

The purpose of this investigation, which was essentially completed at the time of the ANPRM release, was to assess the noise exposure requirements, and regulations which civil transport helicopters might face in the 1975-1985 time period to meet possible certification requirements and/or community acceptance.

In order to evaluate the potential of existing helicopters, or their derivatives, to comply with these requirements, a study based on the Boeing-Vertol Model 347 helicopter was included in the program. The Model 347 (Figure 1), a 50,000 pound tandem rotor helicopter which in a commercial version will carry about 50 passengers, is derived from the U.S. Army's CH-47 (Chinook). One of the objectives when the 347 was developed, was reduction of rotor noise. This was effected by increasing the height of the aft pylon by 30 inches, and stretching the fuselage by 110 inches to minimize blade vortex interaction between rotors. Additionally, the CH-47 3-bladed rotor was replaced with a 4-bladed rotor, which in turn



**BOEING MODEL 347  
ADVANCED TECHNOLOGY HELICOPTER**



**BOEING MODEL 347 — CIVIL HELICOPTER**

permitted a reduction in hover tip speed from 738 to 690 feet per second. The results were almost complete elimination of the banging characteristic associated with Chinook rotor noise, as well as a reduction in the non-banging components, generally termed rotational and broadband noise.

The CH-47 is in the size range considered for a commercial carrier. Considering the 347's involvement in a rotor noise reduction program, and the demonstrated results, it makes an excellent subject for a study of the potential of civil helicopters to meet a transportation need while observing reasonable noise restrictions.

### NOISE CRITERIA FORECASTS

In order to assess the ability, or potential of current military helicopters (or their derivatives) to meet the noise requirements that may be imposed on future civil operations, it is necessary to have a general idea of what these noise limits might be. At the time of this study however, there are no official criteria that could be used as a basis for such a study. Therefore, it is a necessary first step to engage in a forecasting, in order to evaluate the noise limits the helicopter may face during the 1975-1985 decade.

There are two separate types of criteria: Certification and Community Acceptance.

#### Certification Criteria

Certification criteria for noise is the responsibility of the Federal Aviation Administration (D.O.T.). The authority for inclusion of noise as an item in certification was set by Public Law 90-411, which amended the Federal Aviation Act of 1958 to require aircraft noise abatement regulations. This regulation later resulted in the issuance, by the FAA, of regulations which were applicable to subsonic jet airplanes (Reference 1).

Historically it is also evident, that certification limits are generally set so the better designs at any given point in time will certify, eliminating those models which fail to properly apply the available methodology. Certification criteria levels therefore can be expected to go down, as noise reduction technology improves.

Certification criteria can be expected to be in the form of noise limit(s) measured at arbitrary distances, while the aircraft is performing specified maneuvers.

Compliance with certification criteria does not ensure community acceptance, but it does monitor all aircraft against a common standard.

At the time of the preparation of this report, it should be noted, the FAA has announced an Advanced Notice of Proposed Rule Making (ANPRM 73-32), which calls for noise certification of short haul aircraft. The ANPRM, however, does not indicate that the FAA has selected a specific measurement system, a method of certification testing, or allowable limits. Therefore, it is necessary for this study to assume the most logical certification criteria.

The current FAR 36 regulation for subsonic jet airplanes embodies a three point measurement system illustrated in Figure 2. For application to VTOL aircraft, it is envisioned that a similar arrangement will be employed. Since some helicopters display considerable acoustical dissymmetry, due to the direction of main rotor rotation and/ or unsymmetrical tail rotor location, it would be advisable to measure levels on both sides of the aircraft.

With regard to recommended distances for measurement, the following considerations are pertinent:

1. Distances should be close enough to provide an aircraft signal well above possible ambient noise, and electrical system noise when sensed with normal microphones.

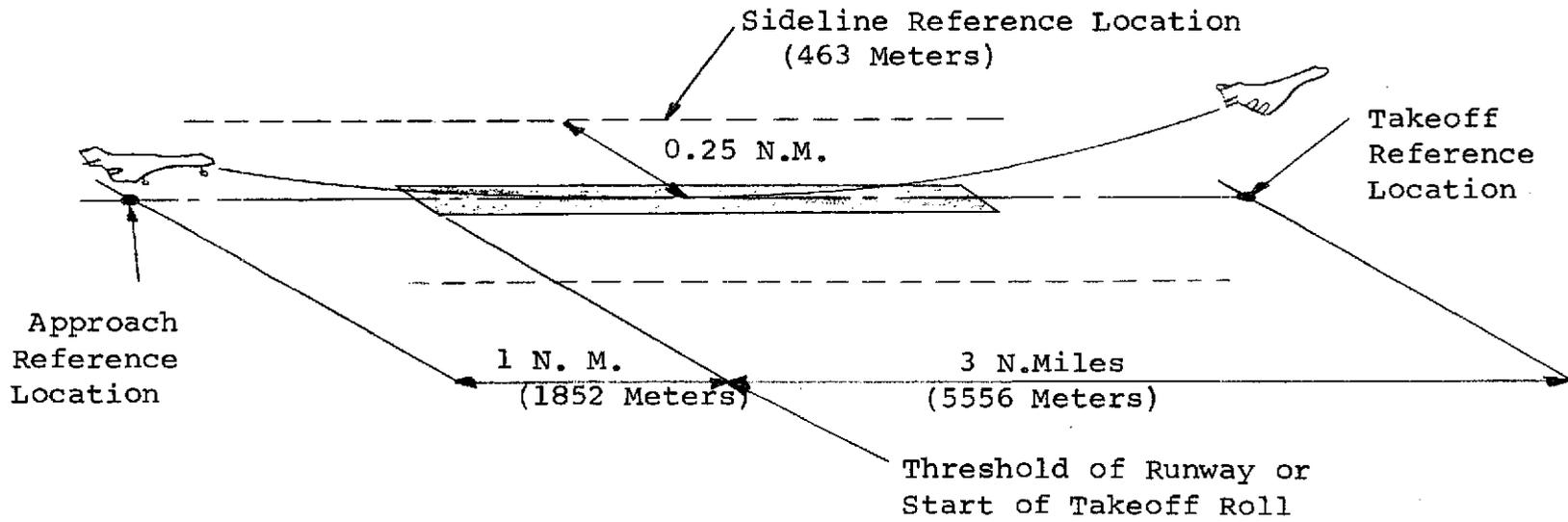


FIGURE 2. THREE POINT NOISE MEASUREMENT LOCATIONS  
SUBSONIC JET AIRPLANES

2. Distances should be close enough to minimize requirements for corrections due to atmospheric, and/or terrain effects.
3. Microphones should be in the acoustic far field, a minimum of three, and preferably five rotor diameters away.
4. Microphones should be distant enough as to be unaffected by rotor downwash.

The microphone locations should bear some reasonable relationship to the locations likely to be typical of the nearest neighbors to a heliport.

Taking all of the above factors into consideration, Figure 3 illustrates a logical, and likely, certification measurement layout for helicopters ranging from 5,000 to 150,000 pound gross weight.

In considering flight trajectory, it is important that all helicopters not be constrained to a single tightly defined trajectory, as with the CTOL aircraft. Doing so deprives the VTOL aircraft of the ability to use its unique flying ability as a noise control device. Since some types of rotor noises are quite sensitive to small changes in attitude, yaw, rate of climb and descent, etc., it will be assumed that any approach and departure that meets flight safety certification criteria may be employed.

With regard to units of measurement, the major precedent lies with Effective Perceived Noise Level (EPNL), which again is the measurement unit applied to subsonic jets by FAR-36.

The only other units which have been seriously mentioned are based on "A" weighted Sound Pressure Level (dBA). The preference for dBA is based on its relative simplicity of measurement, compared with PNL without an apparent degradation in usefulness. In a study of subjective response to V/STOL noise (Reference 2), the authors demonstrated that inclusion of a duration weighting was essential to the correlation between measured data and subjective response. A time weighted dBA, such as used by the state of California in Single Event Noise Exposure Level, however, does in fact correlate as well as EPNL. (This is illustrated in Figure 4.) Application of a time duration factor is more important for a helicopter than for an airplane, since the range of flight

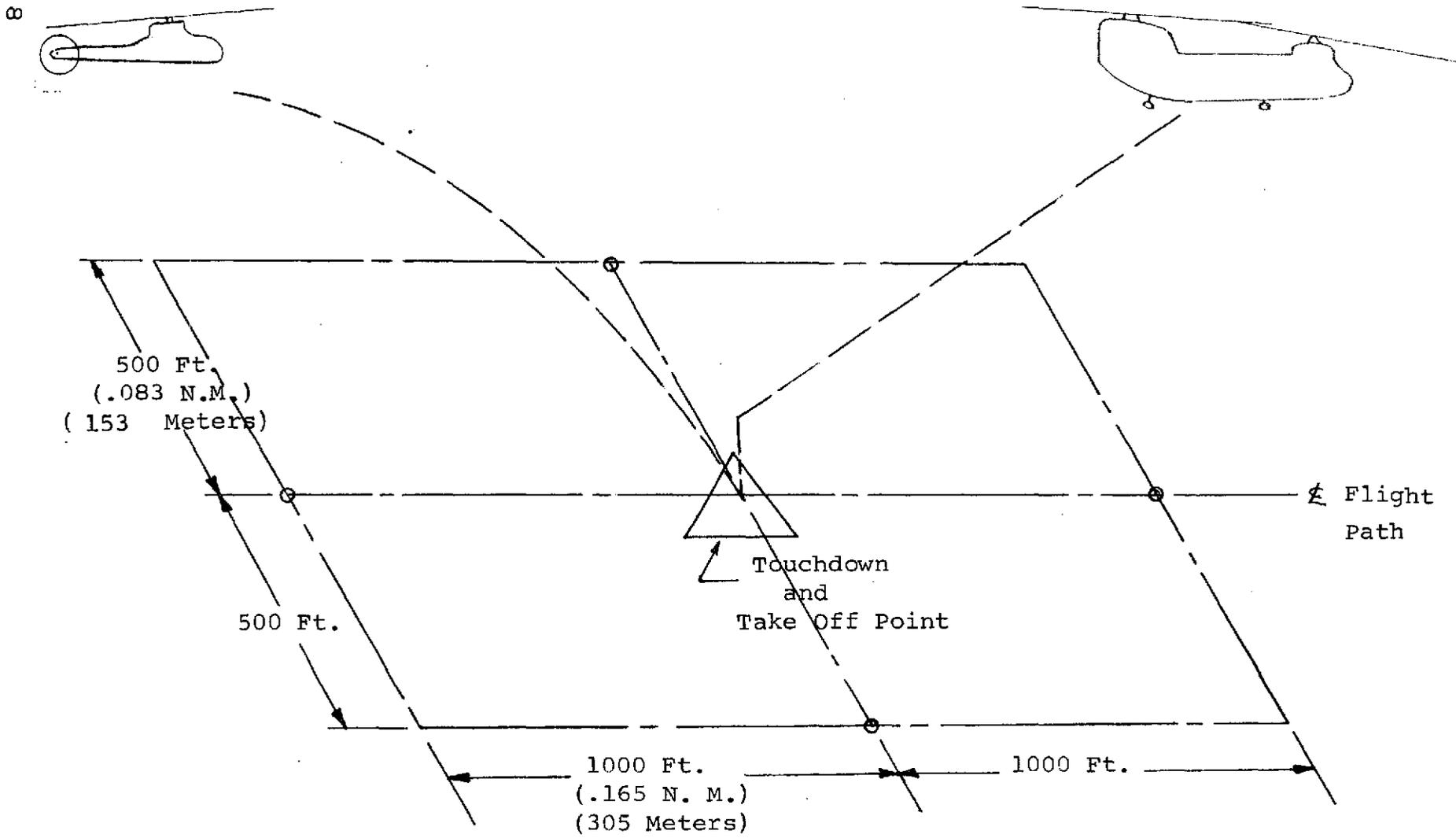
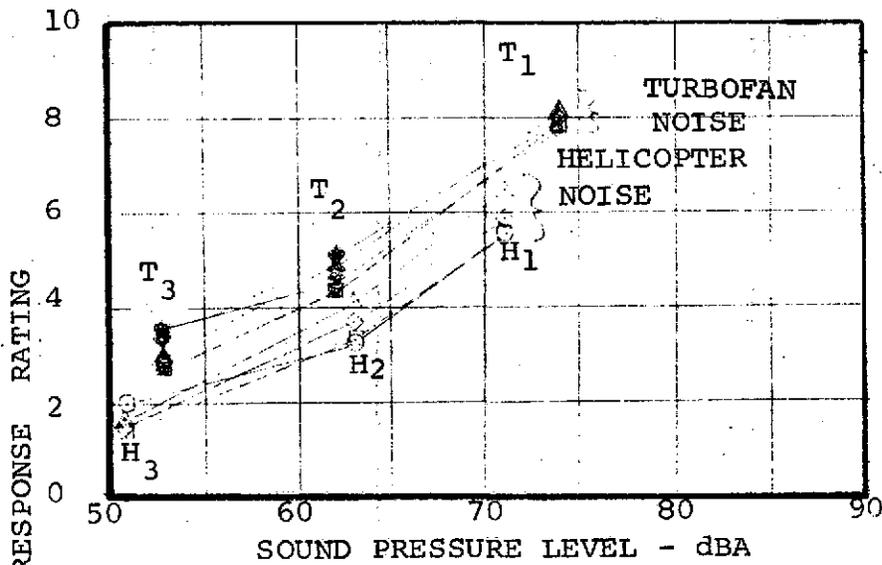
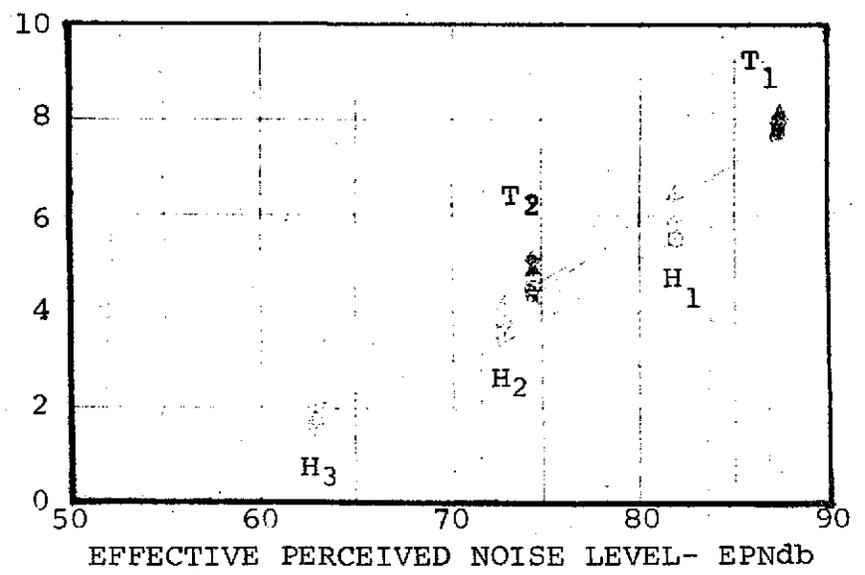
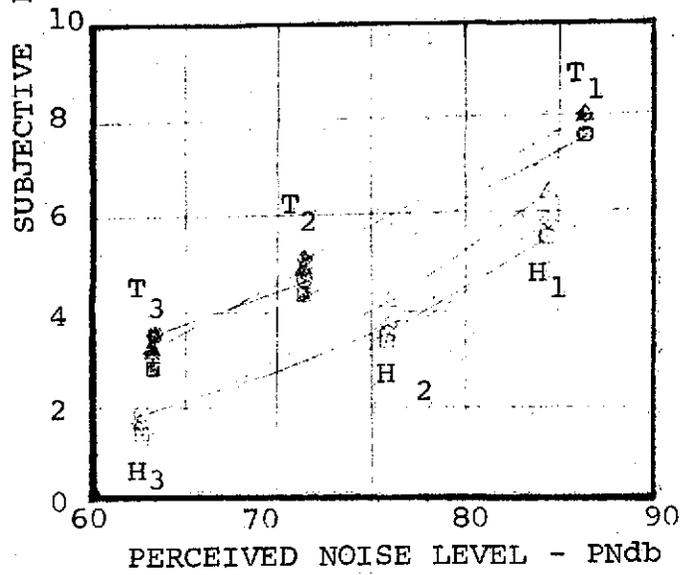
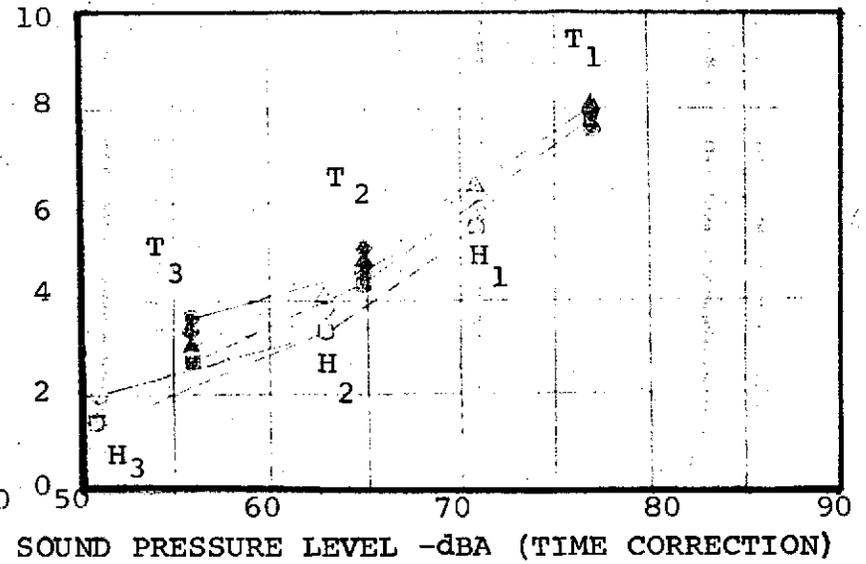


FIGURE 3. POSSIBLE CERTIFICATION NOISE MEASUREMENT LOCATIONS FOR HELICOPTERS

NO TIME FACTOR



TIME FACTOR



trajectories is more varied, and the ability to hover for an indeterminate amount of time exists.

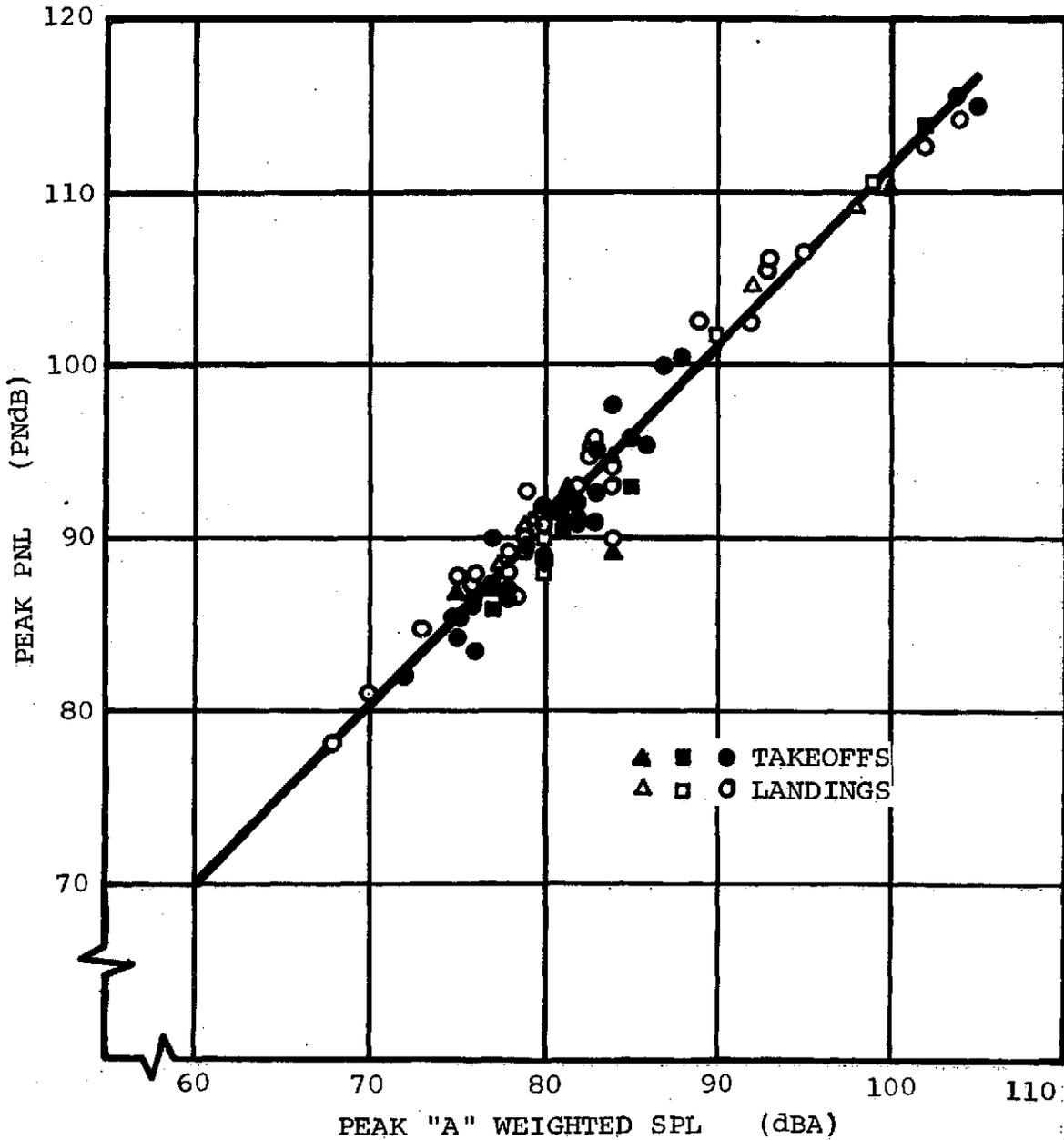
The question of whether a future FAA regulation will be in terms of EPNdB, or time weighted dBA is academic in that they are directly related. Figure 5 presents peak PNL and peak dBA for eight takeoffs and landings of the Boeing Vertol Model 347 helicopter (including three different takeoff trajectories and three different landing trajectories) measured at five locations. Attention should be directed to the high degree of correlation between the two units (dBA = PNL-10). As long as the same time duration weighting factor (e.g.:  $10 \log (t/15)$ ) is used for both measures a similar correlation will be obtained between EPNL and time corrected dBA.

Discussions with the Noise Abatement Staff of the EPA held in October 1973 indicated that they will strongly recommend that EPNL measurement units, consistent with subsonic jet regulations, be employed for VTOL aircraft noise certification.

EPNL also has the added unofficial, but noteworthy status of having been adopted by the Society of Automotive Engineers, and published as ARP 865. Additionally it has been the unit used in such documents as the Joint DOT-NASA Civil Aviation Research and Development Policy Study (Reference 3).

The main arguments for dBA-based measurements are, that they are simpler to make, require less sophisticated equipment, and can be more easily compared with non-aircraft data. These arguments, while true, are more applicable to community noise criteria than FAA certification procedures, as will be discussed in the section on community noise.

It is the opinion of the authors that neither EPNL or dBA properly reflect the best measurement of helicopter noise. This is due to the fact that both measures de-emphasize the low frequency portion of the spectrum, which is characteristic of rotor noise. (See Appendix A). Since it would not be wise to change from one inadequate measure to another, and an optimum measurement system for helicopters has not been developed, for purposes of this program it will be assumed that the FAA will not depart from the EPNL measurement, and will apply it at the locations shown in Figure 3.



CORRELATION BETWEEN PERCEIVED NOISE LEVEL  
AND "A" WEIGHTED SOUND PRESSURE LEVEL FOR  
VARIOUS HELICOPTER TAKE-OFFS AND LANDINGS

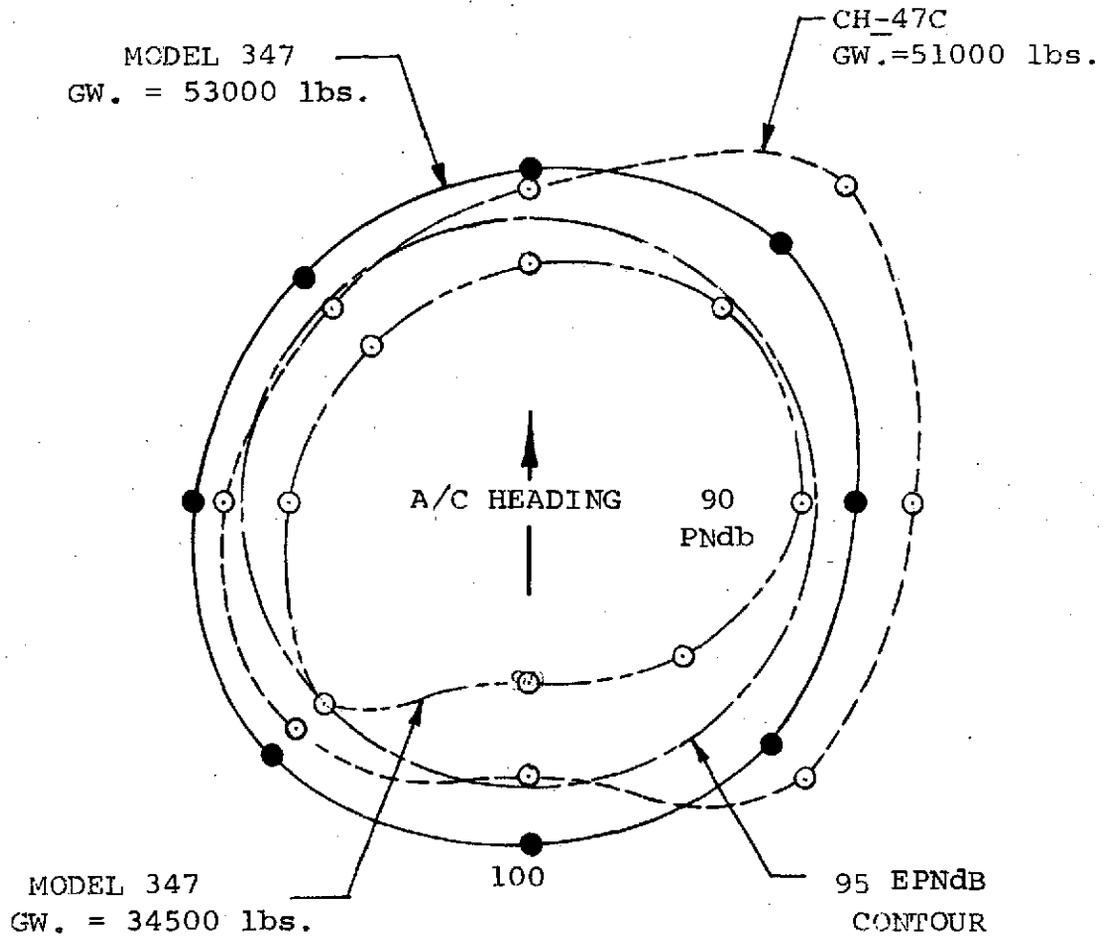
FIGURE 5

A probable initial limit is 95 EPNdB. This number has been considered as an unofficial guideline since 1970, when an FAA letter suggested that industry might use this value for planning purposes. More pertinent, perhaps, is the consideration that the initial values should be stringent enough that only the quieter current aircraft can comply, and yet not so conservative that it is unattainable. (Figure 6 illustrates the application of this criterion to the Boeing Vertol Product Line which was described in the introduction.) The U.S. Army CH-47C "Chinook" helicopter with levels up to 104 EPNdB clearly cannot comply. The current Model 347 at 53,000 pounds ranges up to 99 EPNdB and is a definite improvement, but also exceeds the 95 EPNdB target. However it is possible, to meet the 95 EPNdB criteria with the current Model 347 at 34,500 pound gross weight. As will be demonstrated in a later section of this report, application of currently known technology can be employed to also meet 95 EPNdB at 500 feet at a gross weight of 53,000 pounds. The above discussion serves to illustrate that 95 EPNdB will provide a critical yet attainable goal for initial certification criteria.

It is expected that in its role of setting incentives, certification criteria will become more stringent with time. Figure 7, reproduced from Reference 3, indicates a 1981 goal of 80 EPNdB for research in VTOL noise of aircraft up to 75,000 pounds gross weight. Figure 8 presents two rationales which might be applied to projecting future criteria limits. Each rationale starts with 95 EPNdB in 1975 (Point 1). The NASA/DOT 1981 research goal, if attained, would probably require another 5 years to completely implement in production aircraft (Point 2). Meanwhile, improvements utilizing existing technology can be applied to obtain a reduction of 5 EPNdB by 1980 (Point 3). The NASA/DOT goal is an extremely ambitious one. This goal, which can only be obtained by a massive research effort, will require aircraft designed from inception to utilize the research results. If government and industry do not provide the necessary funding for a "crash" program, then certification criteria will have to recognize this fact. In this event it is still possible to expect that aircraft designed for the future might, with reasonable support and sponsorship, effect an additional 5 EPNdB by 1985 (Point 4) and 5 EPNdB more in the decade following (Point 5).

Despite all efforts, it can be expected that the attainment of each goal will carry some penalty over optimum

EXTERNAL NOISE LEVELS  
 500 FOOT RADIUS  
 EPNL - 15 SEC.



110

FIGURE 6 COMPARISON OF EXTERNAL NOISE - BOEING HELICOPTERS

• FAR PART 36 (NOV. 1969)

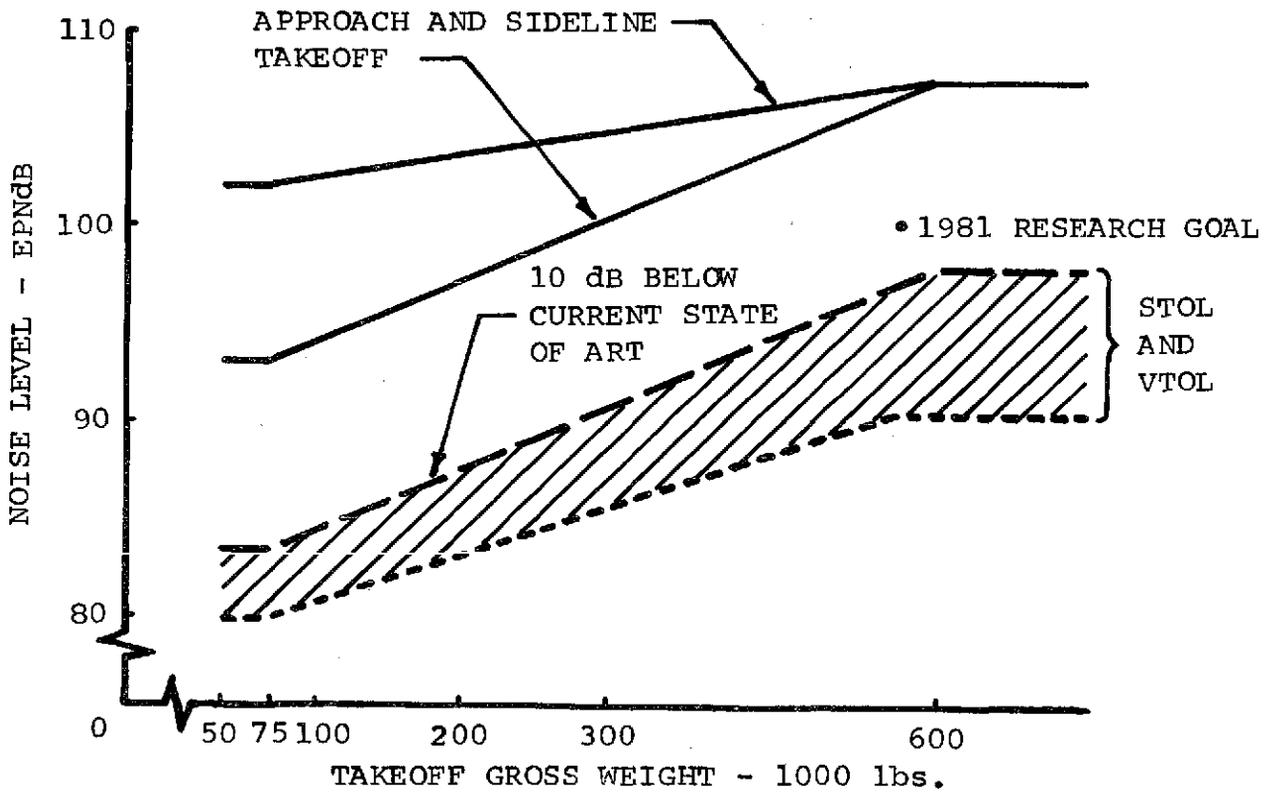


FIGURE 7. AIRCRAFT NOISE CRITERIA FROM REF. 3

EFFECTIVE PERCEIVED NOISE LEVEL - EPNdb AT 500 FT.

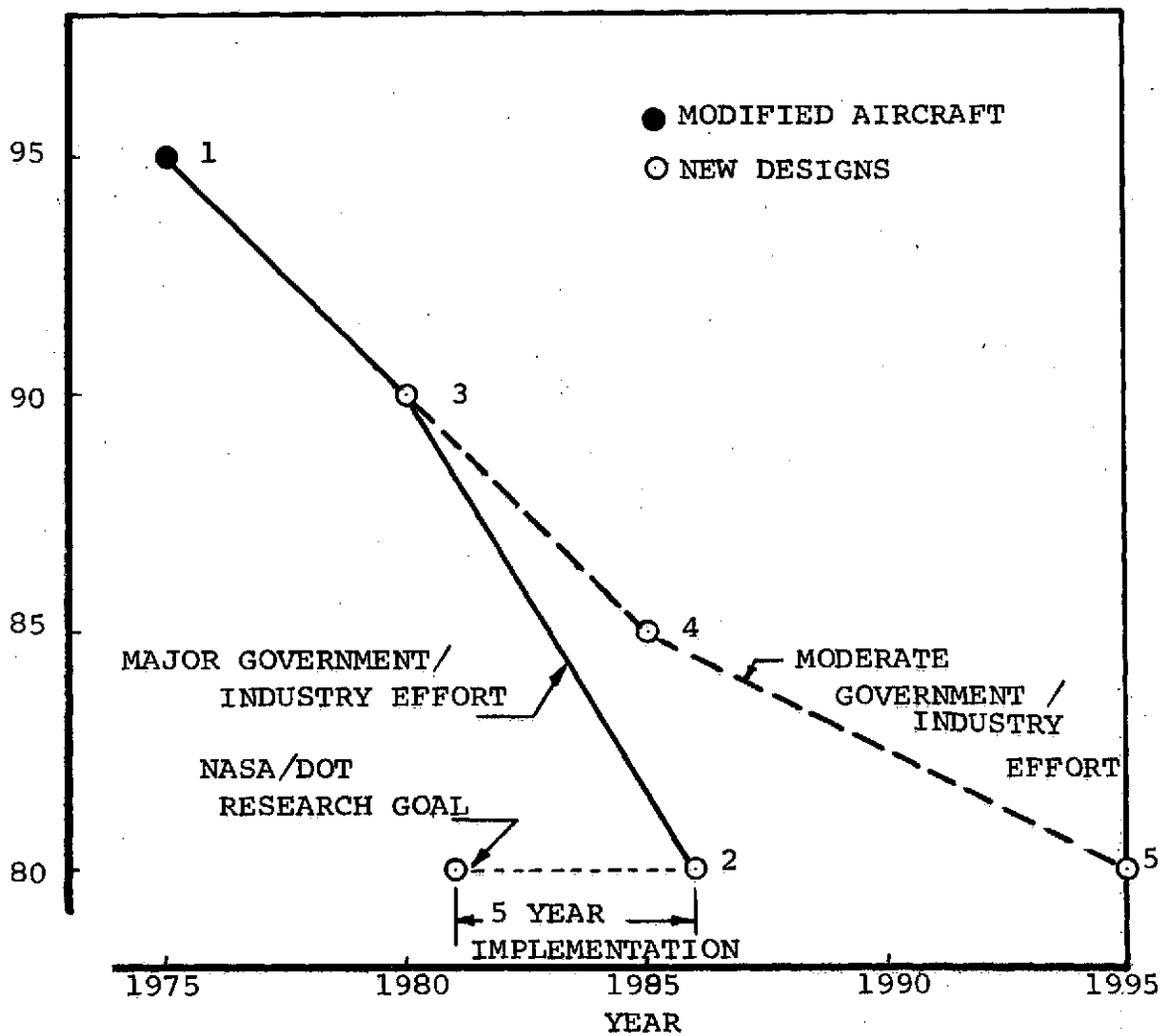


FIGURE 8 PLAN FOR FUTURE CERTIFICATION NOISE LIMITS

achievable performance. A purpose of the criteria will be to assure manufacturers that their competitors must meet the same goal. In effect this places the competition in the area of meeting a specified noise level at minimum cost, and precludes trading off noise for other considerations.

### Community Noise Criteria

Consideration of community noise criteria involves much broader considerations than certification. While certification should be based on an objective measurement of a single event measured in a low ambient noise, community noise evaluation must consider the following:

- Aircraft Noise Signature
- Ambient Noise
- Frequency of Events
- Time of Day/Night

In addition, the measurement system must have subjective validity, and even then an apparently reasonable criteria may fail to assure public acceptance. The degree to which people will accept an intrusion by an aircraft, however slight, can possibly be a reflection of their attitude towards the aircraft operation, or towards society in general.

In an attempt to bring some order to this complex problem, several investigative techniques were employed. The methods applied included a literature review, a letter survey, interviews with key individuals, and the results of research in subjective response to helicopter noise. These programs were conducted both as company sponsored research and as NASA sponsored programs (References 2, 4 and 5). The literature search covered many documents of varying usefulness, and are listed in the Bibliography. Those documents from which specific information was used are also listed in the Table of References. Reference 6 is a major compilation of the noise and annoyance rating methods in use, and will be used in lieu of the original works where applicable.

Discussions were held with representatives of the EPA, Washington, D.C., the Board of Trade Personnel, and the Greater London Council, London, England.

All criteria, or regulations aimed at limiting rotor noise fall into one of the following categories:

1. Single Event Noise Limits based on the maximum sound level attained on the ground during a takeoff, landing or flyover, irrespective of the time duration of the sound or the number of times it occurs.
2. Multiple Event Limits based on either the total or average sound level integrated over a specified time period (e.g. 24 hrs.).
3. Multiple Event Limits based on the difference between the aircraft and ambient sound levels integrated over a specified time period.

There are a great number of these rating methods in existence today (Reference 6 contains a list of fifteen), the difference between most being rather subtle. Table I presents a summary of similarities, and differences, of most of the community noise rating methods which might be considered as likely candidates for use in the United States. Figure 9 for example, shows that eight of these methods would differ little in the control they exercise over limiting flight operations for an aircraft generating a specified acoustical signature.

The simplest type of noise regulation is probably represented by the "Nuisance" ordinances enacted by many local governments. These ordinances generally state that noise levels shall not exceed a certain maximum level, expressed either in dBA or full octave spectra. In some cases a lower value is used at night. In the United States the jurisdiction of local municipalities over aircraft noise is somewhat unclear, and many of these ordinances (such as Newcastle County, Delaware) have been drafted, but are not enforced, pending clarification from the courts.

An example of this regulation in use is the one put into effect by the Greater London Planning Council, which limits operation to helicopters not exceeding 81dBA at 500 feet, or 75 dBA at 1000 feet with a maximum of 50 flights per day and no flying between 2100 and 0700 hours.

In considering the remaining methods, it is interesting to note that one of the most ubiquitous methods listed is also

TABLE I. FACTORS INCLUDED IN VARIOUS  
COMMUNITY NOISE RATING METHODS

NAME	FACTORS INCLUDED		Temporal Distrib.	Time of Day	Flts/Hr or/Day	Season	Previous	Community Exposure	Ambient Level	Ambient	Temporal Distrib.	Impulse	Community Attitudes	Basis for Analysis
	Symbol	Units												
London Guideline		dBA		✓	✓									Maximum Level
Composite Noise Rating	CNR <sub>C</sub> CNR <sub>A</sub>	dBA PNdB		✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓				✓		Maximum Level
Community Noise Equivalent Level	CNEL	dBA	✓	✓	✓									Average Energy
Noise Exposure Forecast	NEF	EPNdB	✓	✓	✓									Total Energy
Weighted Equivalent Perceived Noise Level	WECPNL	EPNdB	✓	✓	✓	✓								Average Energy
Noise Pollution Level	NPL	(any)	✓		✓				✓		✓			Average Energy
Day-Night Level	L <sub>dn</sub>	dBA	✓	✓	✓				✓		✓			Average Energy
Local "Nuisance" Ordinances		dBA or SPL		✓										Maximum Level
Single Event Noise Exposure Level	SENEL	dBA	✓											

WECPNL	NI	B	Q	N	NNI	NEF*	CNR
103	90	70	95	112	70	55	130
93	80	60	85	102	60	45	120
83	70	50	75	92	50	35	110
73	60	40	65	82	40	25	100
63	50	30	55	72	30	15	90

\* For 110 EPNdB Flyover

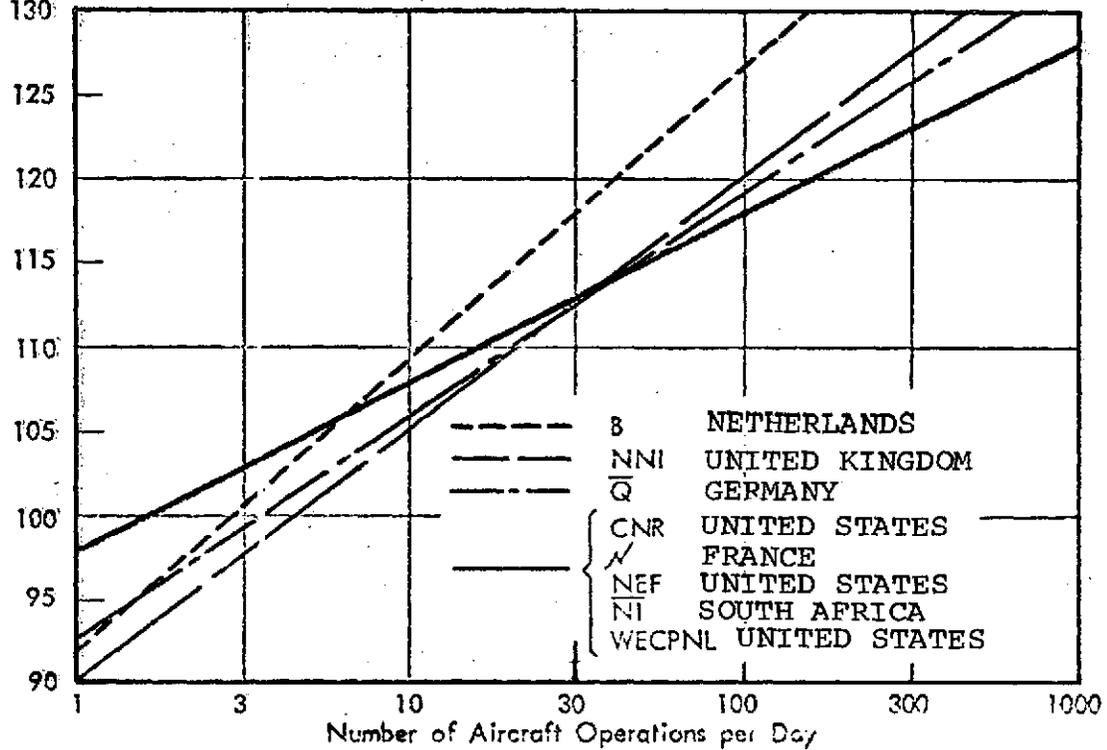


FIGURE 9. COMPARISON OF VARIOUS NOISE EXPOSURE INDICES (FOR A FLYOVER NOISE LEVEL OF 110 PNdB, EFFECTIVE DURATION OF 10 SECONDS, AND VARIABLE NUMBER OF OPERATIONS).

one of the earliest, namely Composite Noise Rating. This method, through sets of weighting factors, attempts to account for many community factors, and even attitudes. The noise measurement, however, was based on maximum octave band spectrum, and did not consider exposure time. As discussed previously, (and illustrated in Figure 4) it has been shown that the temporal pattern of VTOL noise can not be neglected for community noise evaluations.

The major concept separating the remaining methods is the inclusion of ambient noise. If one is trying to comparatively evaluate different aircraft, this factor should not be included and CNEL, NEF, SENEL, or WECPNL may be used to conduct tradeoffs. The subject of concern, however, is expected community response, where ambient noise can be of utmost importance. The ambient noise not only plays a role in masking the aircraft noise, but there is also the philosophical argument, that VTOL noise may be only one of several sources of acoustical energy in a given area and may, in fact, not be the major contributor. To attempt to control the environment by limiting one source only, is not only unreasonable, it may also fail to produce the desired results, by attacking the wrong source.

Inclusion of ambient noise then narrows the choice down to Noise Pollution Level developed by D. W. Robinson, (Reference 6) and Day-Night Level ( $L_{dn}$ ) recommended by Task Group 3 of the Environmental Protection Agency's Aircraft/Airport Noise Study Group.

Although the methods are quite similar in concept,  $L_{dn}$  will be used as the basis for evaluating community acceptance of helicopters in this study for the following reasons:

1. The procedures are more rigorously defined;
2. There is a stated long range numerical goal:  $L_{dn} = 60$ ;
3. It is the method which, although not officially released, presumably reflects the recommendations of the Environmental Protection Agency.

In applying the  $L_{dn}$  concept, however, the authors recommend one departure. The  $L_{dn}$  method permits an averaging of day and night data, with a 10 dB penalty on night operation. This still permits a tradeoff of reducing daytime flights to

gain some nighttime operation. Experience with commercial helicopter operation in mid-Manhattan (New York City), and an analysis of the complaints, does not substantiate, that in this particular case, a tradeoff is permissible, or that 10dB is a proper penalty. This may be due to the fact that daytime complaints are associated with interruptive factors, such as speech interference, and distraction. Nighttime complaints may, however, be associated with awakening, or preventing of sleep. At present it appears a wiser course may be to evaluate daytime and nighttime operations separately.

Since the EPA Task Group 3 recommends a long range goal of  $L_{dn} = 60$  for community noise and  $L_{dn}$  is obtained by averaging Equivalent Noise Level ( $L_{eq}$ ) over a 24 hour period while adding 10 dB to the nighttime data, it is suggested that the goal, with respect to this study, be retained in the  $L_{eq}$  format and restated as  $L_{eqDAY} = 60$ ,

$$L_{eqNIGHT} = 50.$$

Since most cities in the United States do not meet the above long range goals, and it is unreasonable to require helicopters to be quieter than other noise sources, an interim criterion is required. A logical proposition would be that the acoustical energy introduced by any new source, or operation, shall fall within the lower 50 percent of the energy contributed by the other sources. Adherence to this procedure would ensure that any new noise producers fall within the lower 50 percent of the existing noise producers, thereby virtually ensuring no numerical increase in  $L_{dn}$ . Furthermore, attention is focused on the true culprit, the major noise producer, even if previously existent. Adherence to this procedure would, in the long run, drive  $L_{dn}$  down.

Therefore, for communities whose  $L_{dn} = 60$  due to non-helicopter noise, an interim criterion of

$$L_{eqVTOL} = L_{eq50} \text{ (ALL OTHER SOURCES)}$$

will be used.

In order to examine the practicality of such proposed limits, an example was worked in the format of Figure 10 whose ordinate is the maximum dBA due to the helicopter, the abscissa being flights per hour. A flight is assumed to consist of an approach, landing, hover and takeoff resulting in

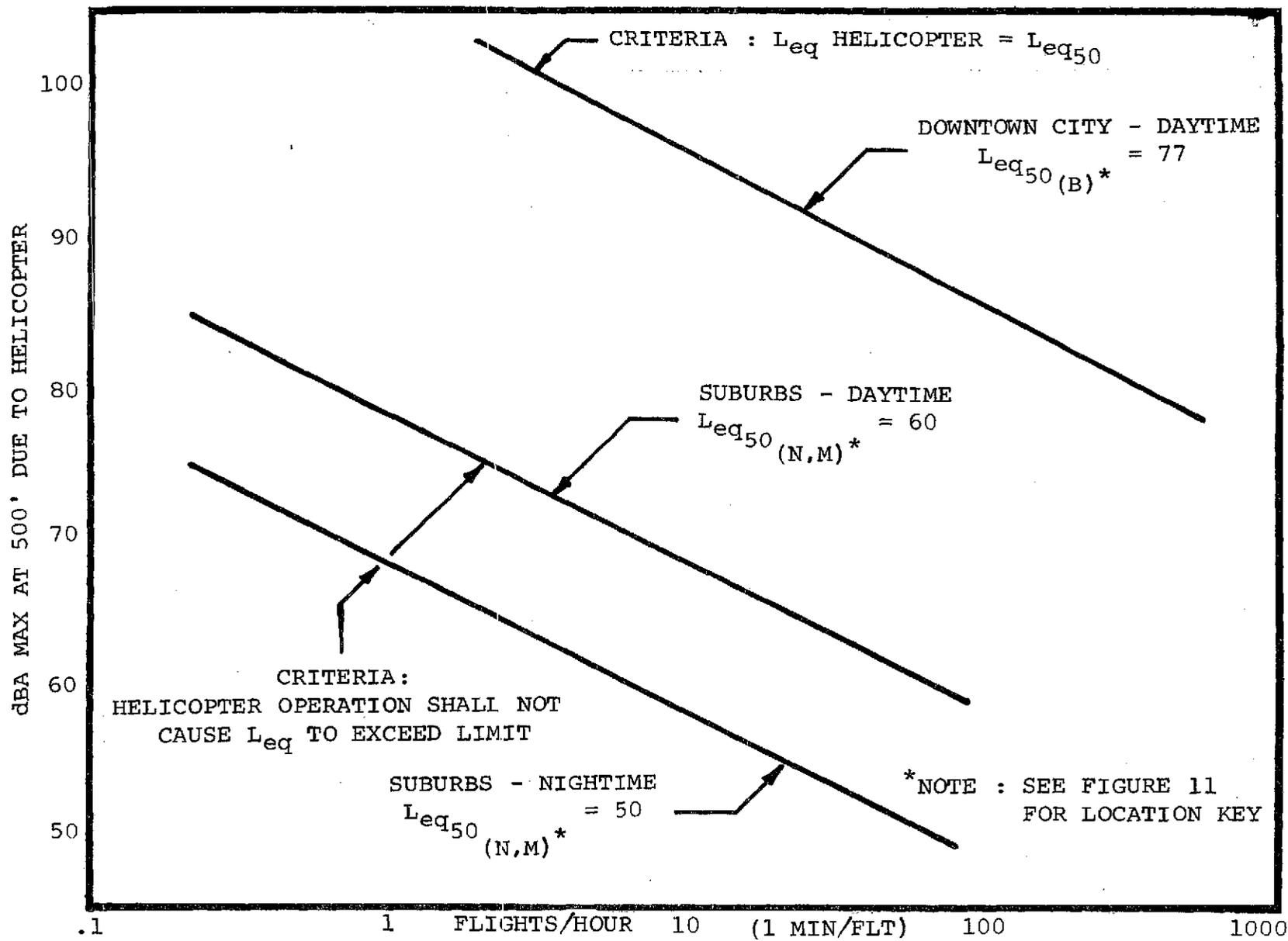


FIGURE 10 EXAMPLE OF APPLICATION OF COMMUNITY NOISE CRITERIA

approximately one minute of exposure to the maximum level. Since helicopters operating near terminals are moving slowly, it is assumed the noise exposure time histories are rectangular, rather than triangular as is typical of airplanes and helicopter flybys.

The calculation method of Reference 6 is used assuming the background noise has a Gaussian distribution:

$$L_{eq} = L_{50} + .115s^2$$

where  $L_{50}$  = the level exceeded no more than 50% of the time

$s$  = 1 standard deviation of the background noise.

Background noise data was obtained from the EPA Task Group 3 Report from which Figure 11 of this report is reproduced:

Three locations were examined. An evaluation would be:

LEVEL dBA MAX	FLIGHT LIMITS		
	City-3rd Flr.	Suburbs Day (M)	Suburbs Night (M-10)
95	30 Flts/Hr		
85	Unlimited	1 Flt/1½ Hrs	
75	Unlimited	2 Flts/Hr	1 Flt/5 Hrs

Figure 12 compares the suggested  $L_{eq}$  criteria with a few other criteria:

- o Specifically,  $CNR_A$  to limit complaints in a city to mild.
- o The "intrusive" level established by a study conducted in Farnborough, England and discussed in Reference 8.
- o The 81 dBA limit imposed by the city of London, England.

Application of these criteria puts less stringent constraints on helicopter operation than the  $L_{eq} = 60$  goal but are more than adequate protection for a person who is located on the lower floors in a major city.

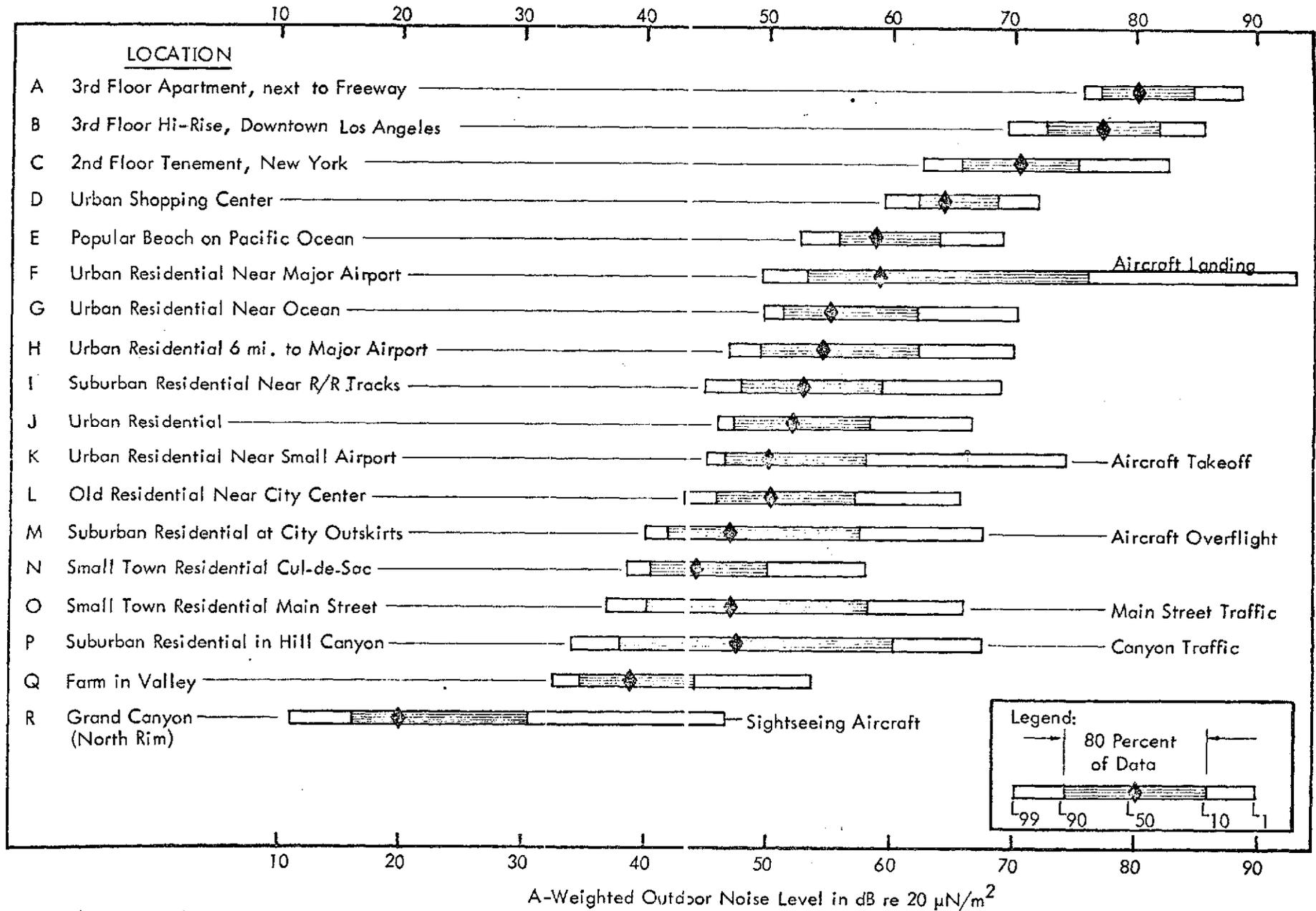


FIGURE 11 DAYTIME OUTDOOR NOISE LEVELS FOUND IN 18 LOCATIONS RANGING BETWEEN THE WILDERNESS AND THE DOWNTOWN CITY.

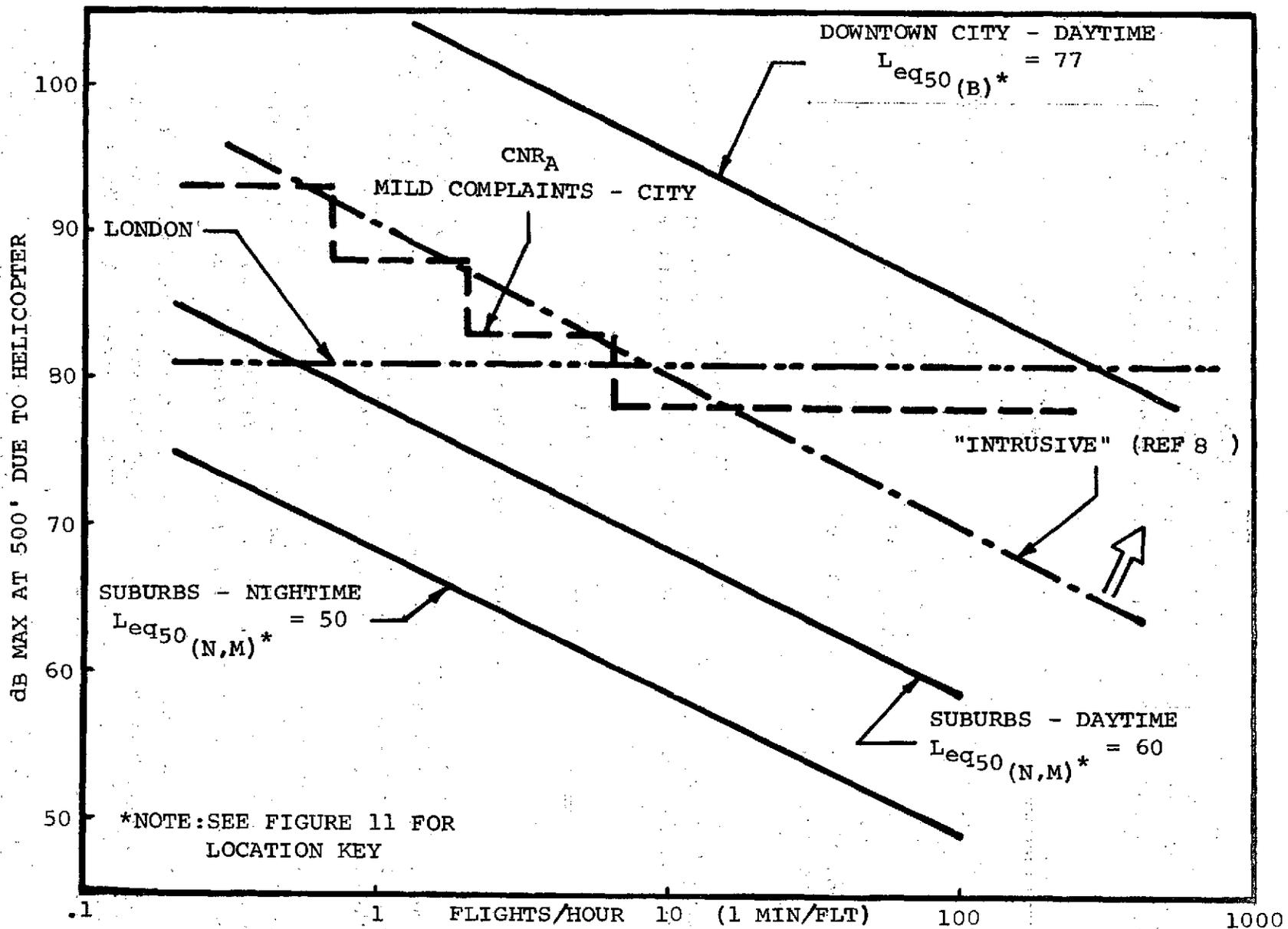


FIGURE 12 COMPARISON WITH OTHER LIMITS

Figure 13 evaluates the limitations which may be imposed on operation, if the certification goals forecast in Figure 8 are just met. EPNdB was converted to equivalent dBA by assuming dBA = PNdB-10 as established in Figure 5. An evaluation of this figure indicates:

NOISE LEVEL	FLIGHT LIMITS			
	Certification Goal	City-3rd Flr.	Suburbs-Day	Suburbs-Night
1975	Unlimited	1 Flt/5 Hrs		
1980	Unlimited	1 Flt/1½ Hrs		
1985	Unlimited	1½ Flts/Hr		1 Flt/5 Hrs
1985-With Major Research Effort	Unlimited	5 Flts/Hr		1½ Flts/Hr

In view of the above analyses it appears that the suggested criteria for community acceptance provides a reasonable basis for design goals for civil helicopters.

#### AIRCRAFT NOISE REDUCTION PROGRAM

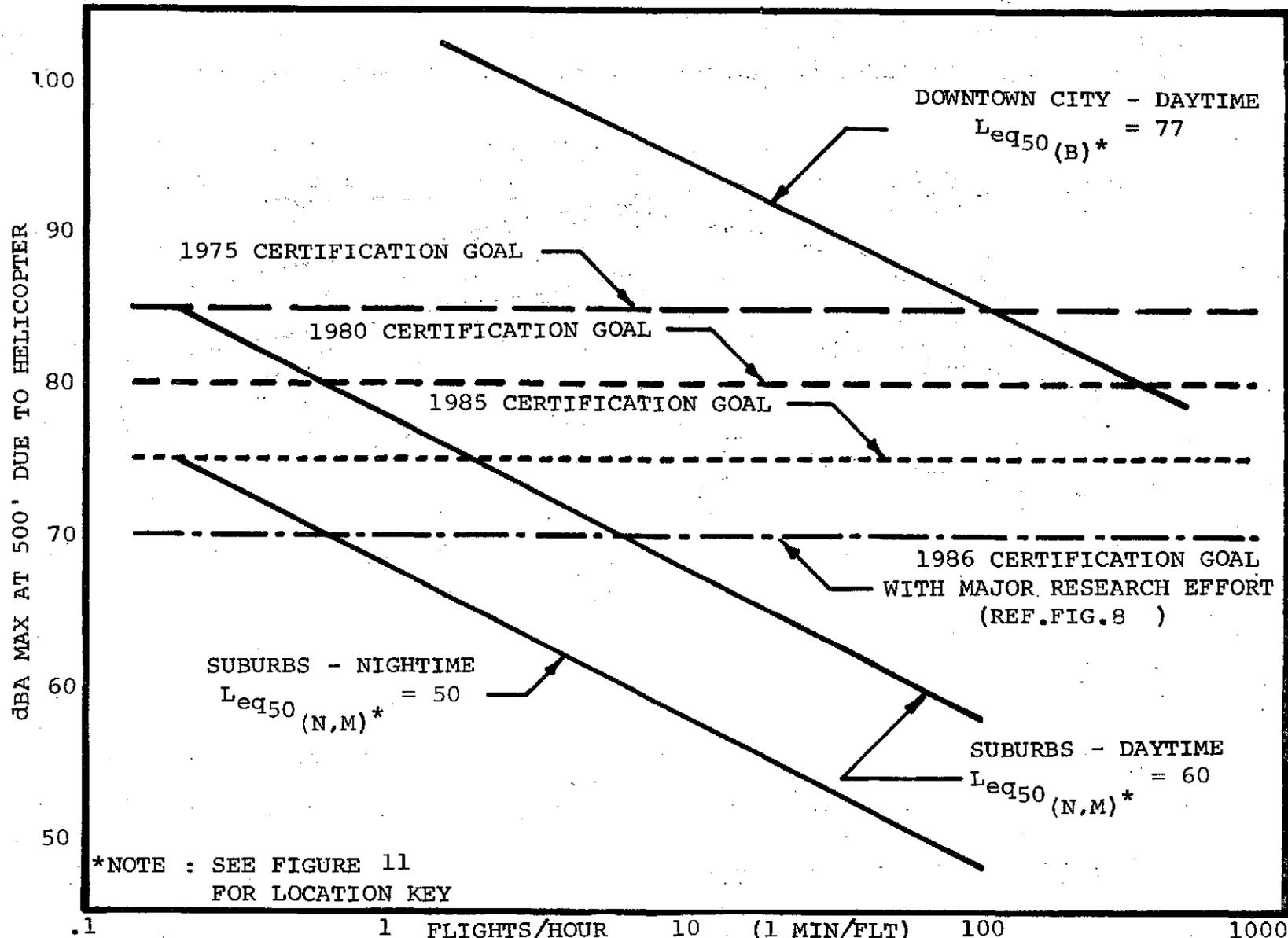
##### Aircraft Noise Signature

Data Acquisition. - Prior to the award of this study contract, The Boeing Vertol Company conducted a flight test program to investigate the effect of flight trajectory on the exterior noise of the Model 347 helicopter.

Three takeoff and three landing procedures, illustrated in Figure 14 were flown. Utilizing a line of five microphones with takeoffs and landings at five different distances from this array, a 25 point data grid was established.

Perceived Noise Level, and Effective Perceived Noise Levels were calculated for each point, and the data interpolated to develop contours of constant level. This data is presented in Figures 15 through 20.

The comparison between Perceived Noise Level and Effective Perceived Noise Level for these data points, is shown in Figure 21. The fact that the two values are approximately



\*NOTE : SEE FIGURE 11  
FOR LOCATION KEY

FIGURE 13. COMPARISON WITH POSSIBLE CERTIFICATION LIMITS AT 500'

- |  |                                       |
|--|---------------------------------------|
| ① 10 DEGREE APPROACH                           | ④ VERTICAL TO 120' - 10 DEGREE CLIMB  |
| ② 9 DEGREE APPROACH TO 500' - VERTICAL LANDING | ⑤ VERTICAL TO 750' - 10 DEGREE CLIMB  |
| ③ 25 DEGREE APPROACH                           | ⑥ VERTICAL TO 1500' - 10 DEGREE CLIMB |

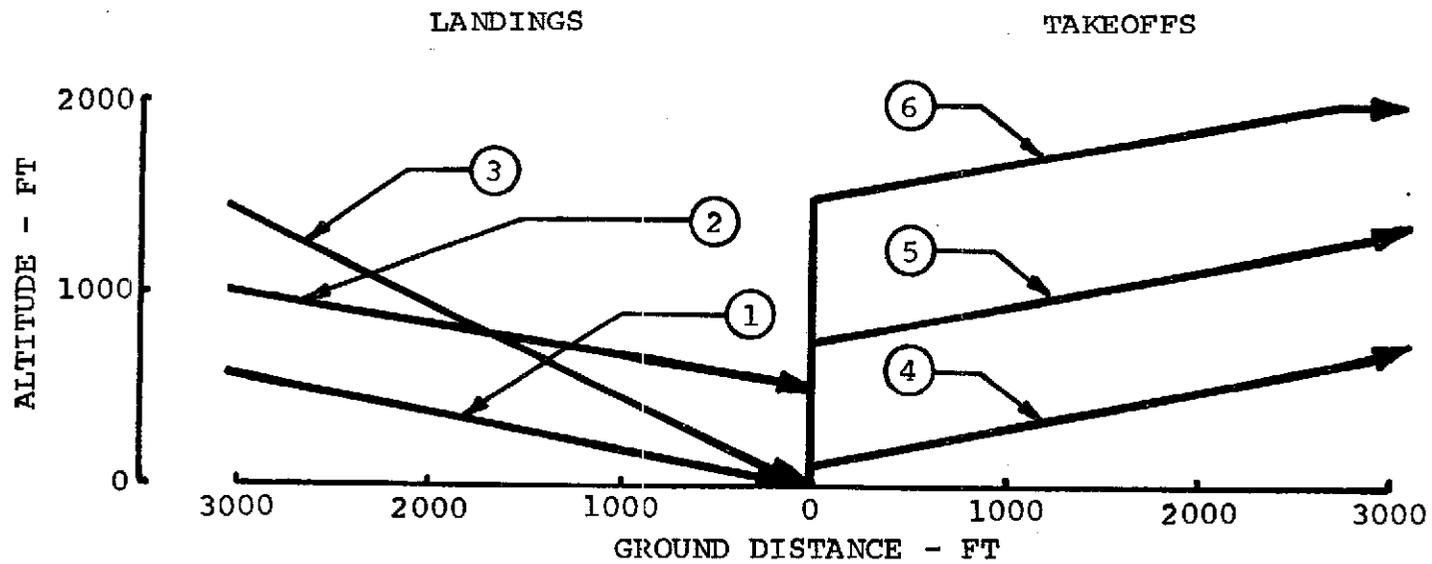


FIGURE 14. MODEL 347 HELICOPTER APPROACH AND DEPARTURE TRAJECTORIES

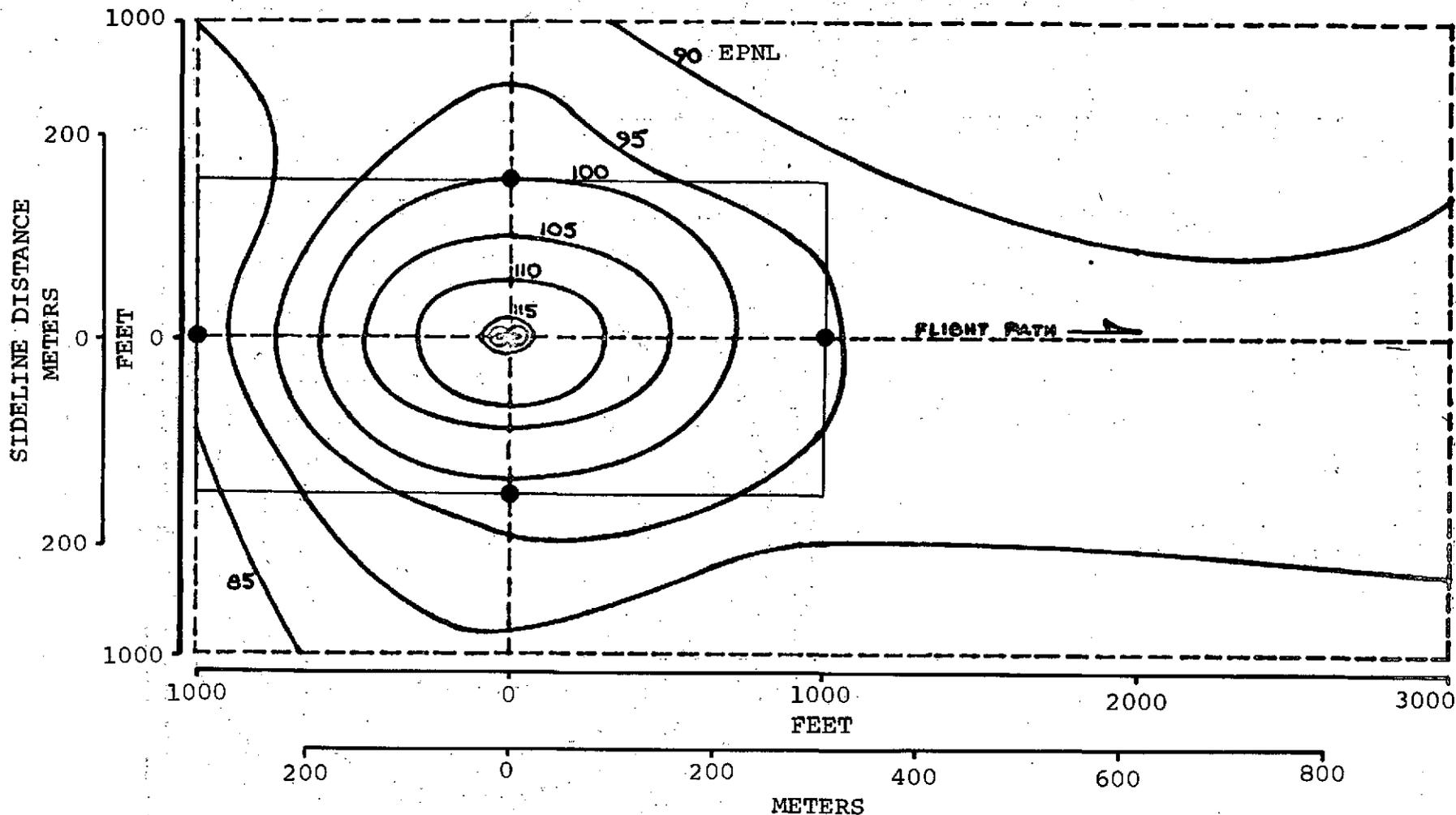


FIGURE 15. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
 VERTICAL TO 120' - 10 DEGREE CLIMB

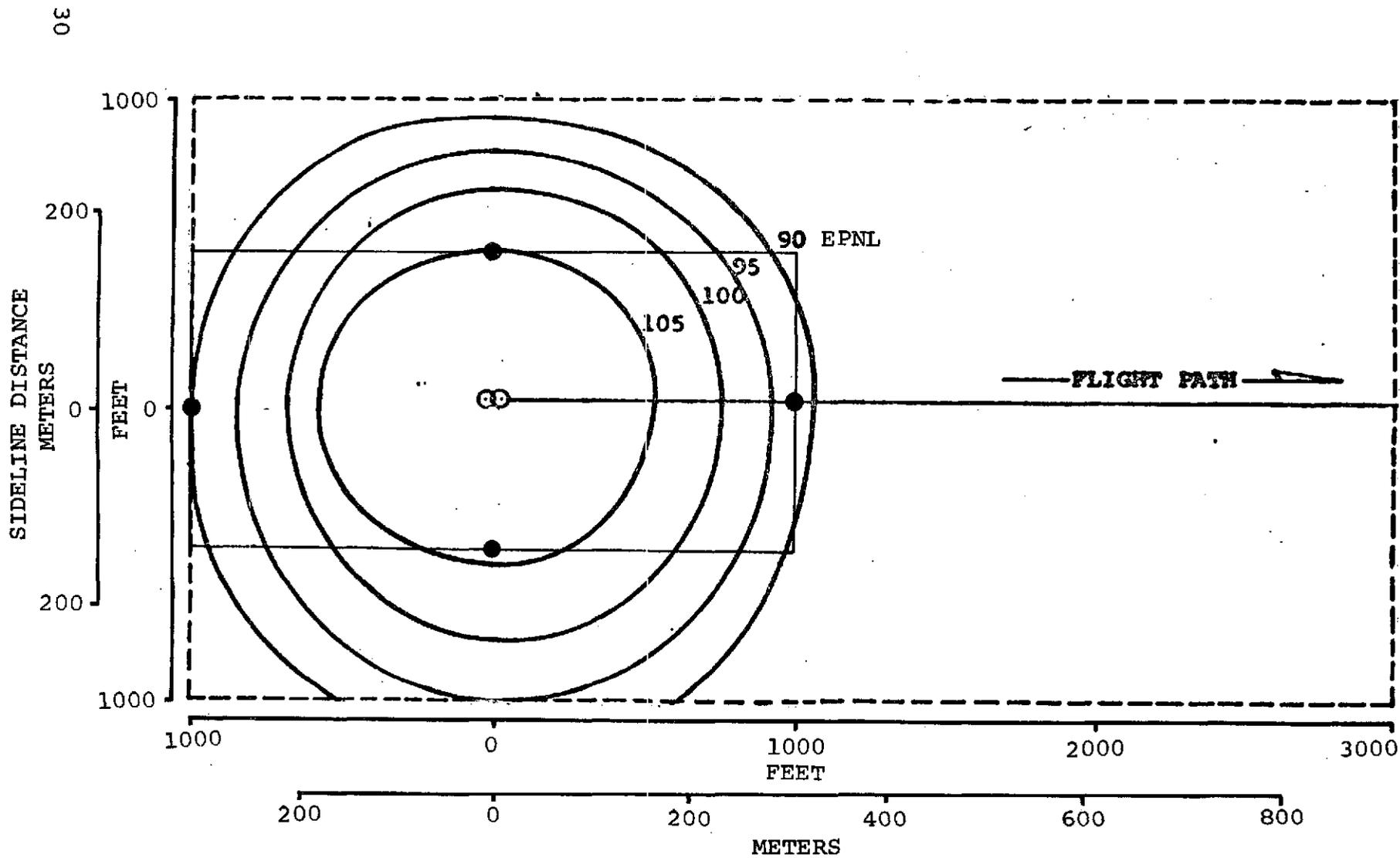


FIGURE 16. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
 VERTICAL TO 750' - 10 DEGREE CLIMB

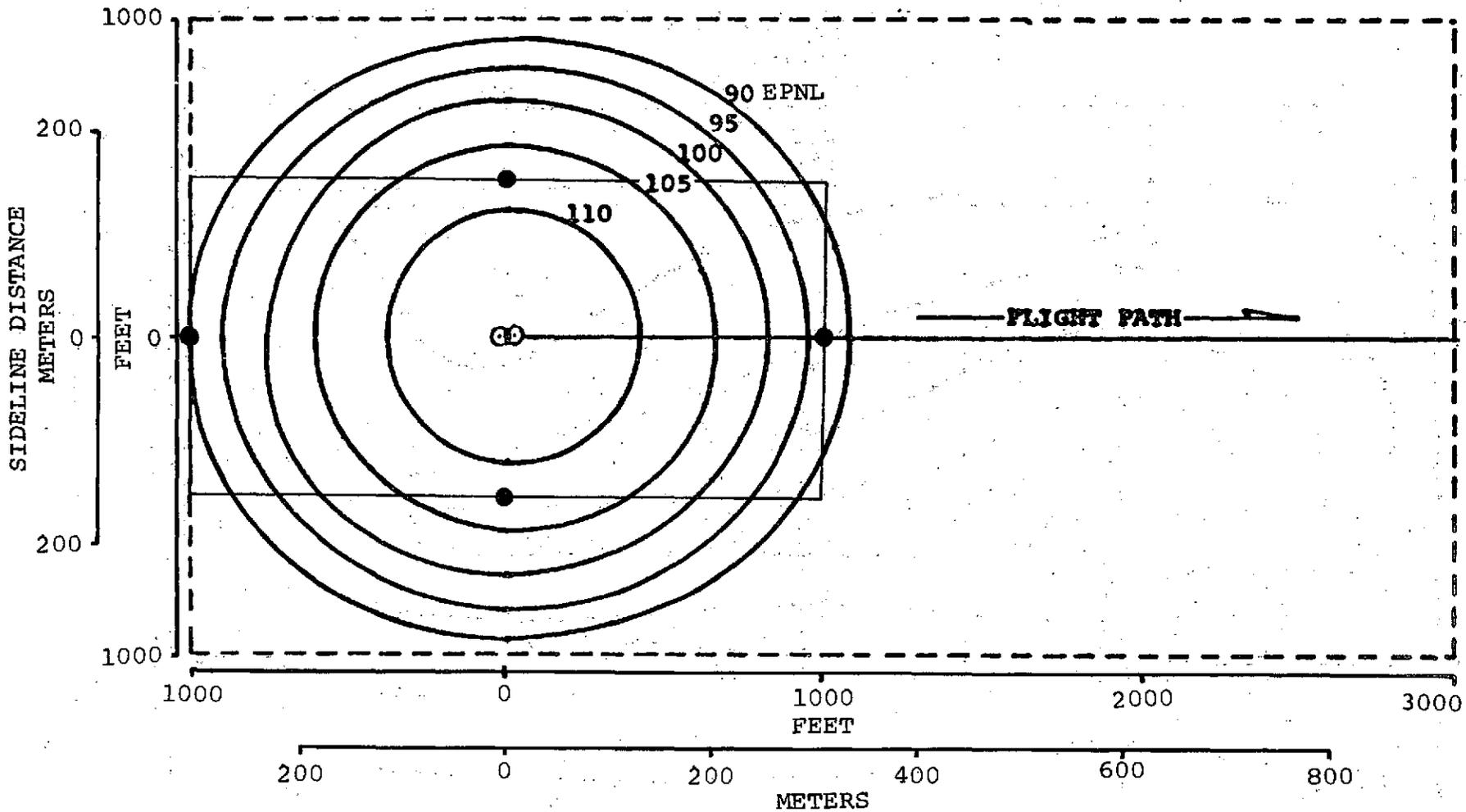


FIGURE 17. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
 VERTICAL TO 1500' - 10 DEGREE CLIMB

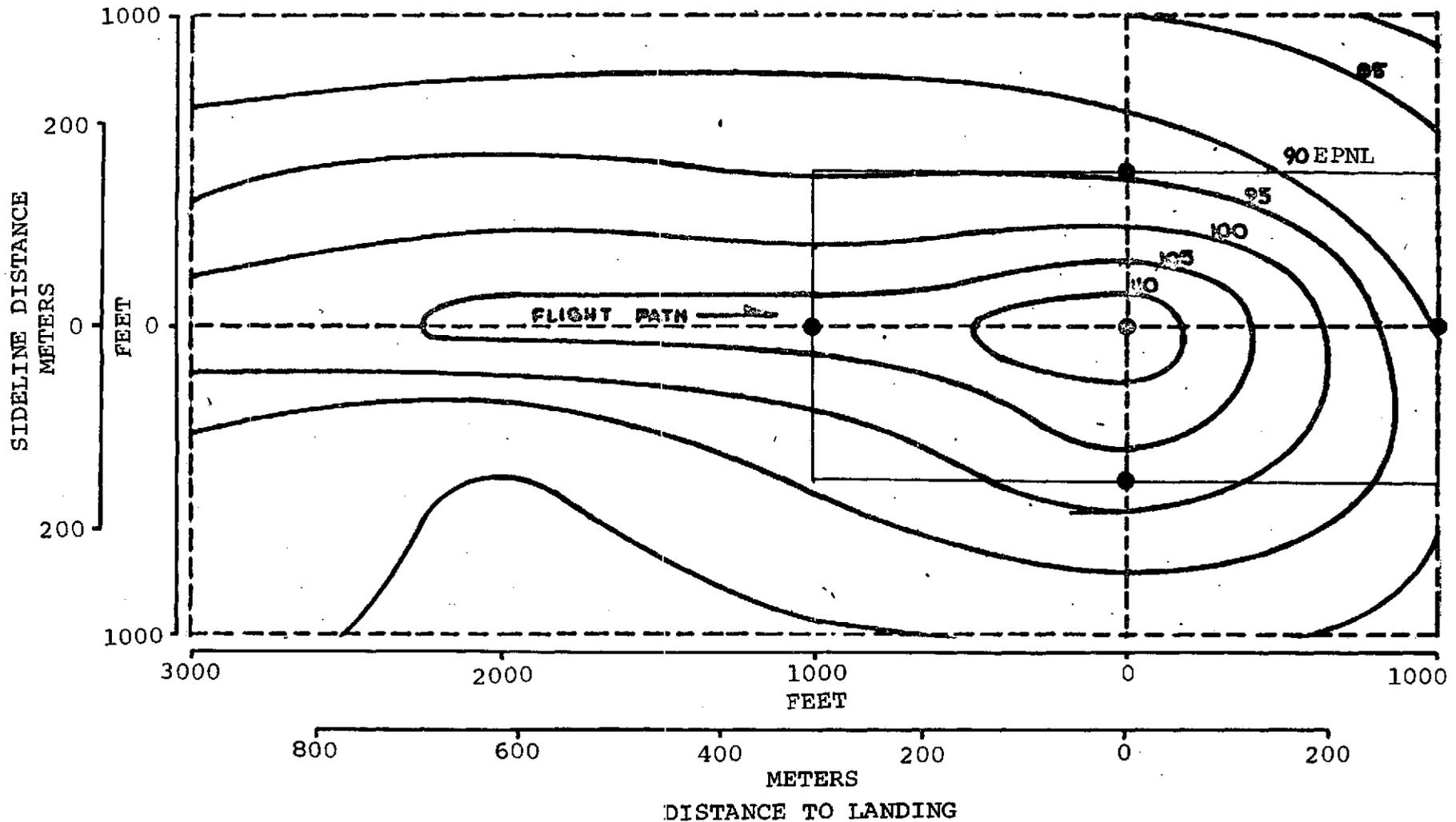


FIGURE 18. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
10 DEGREE APPROACH

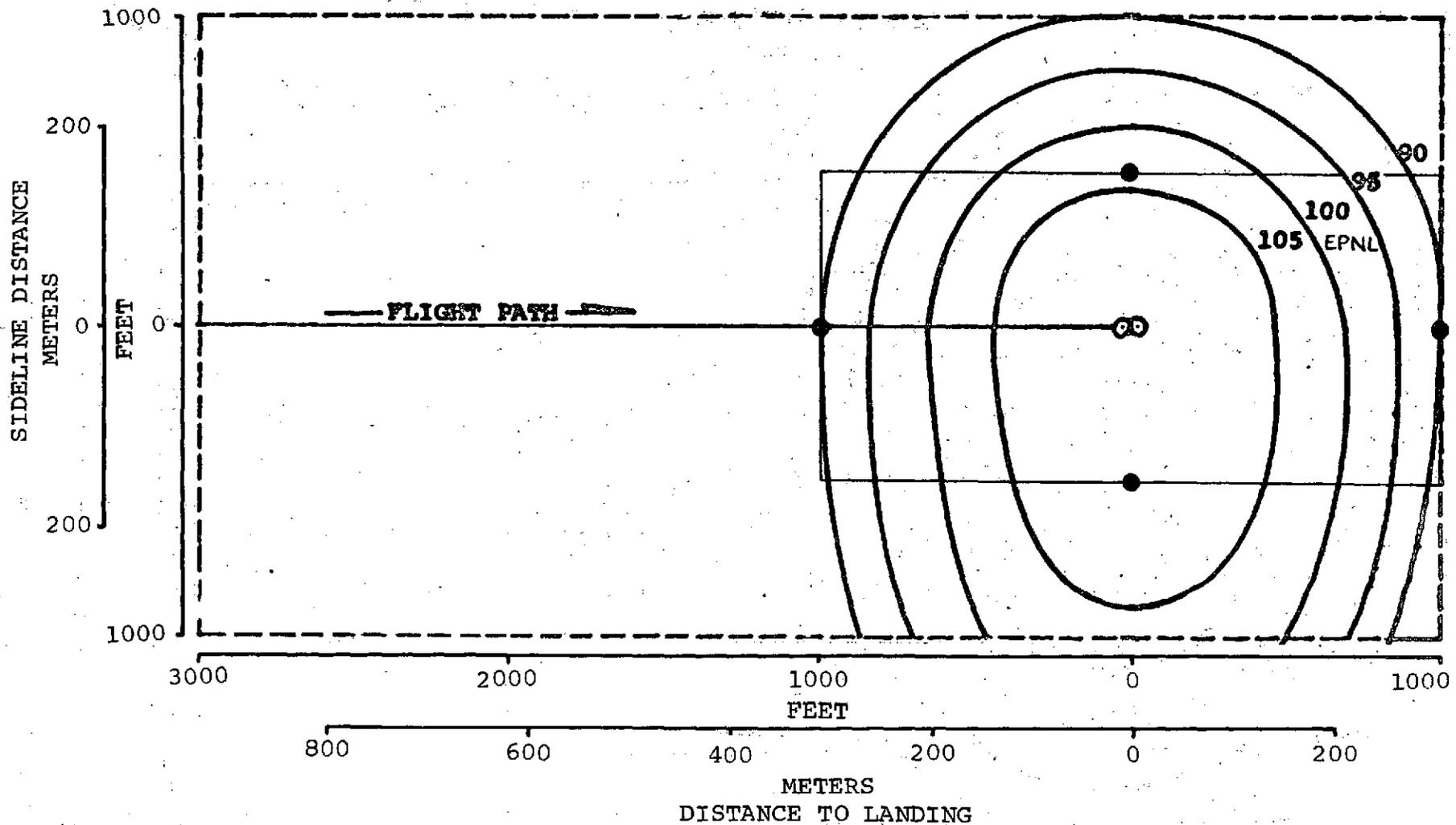


FIGURE 19. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
 9 DEGREE APPROACH TO 500' - VERTICAL LANDING

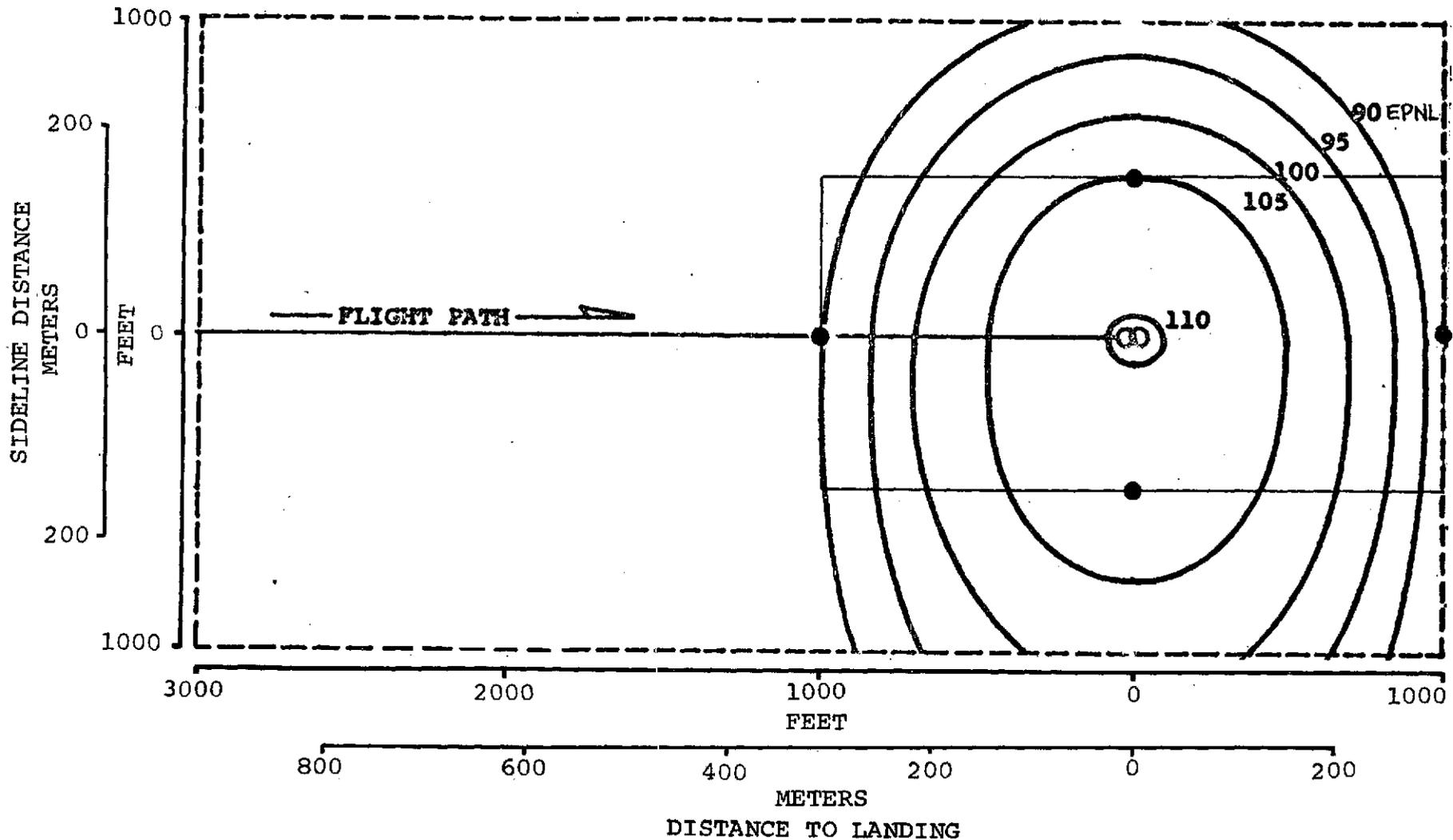


FIGURE 20. MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
25 DEGREE APPROACH

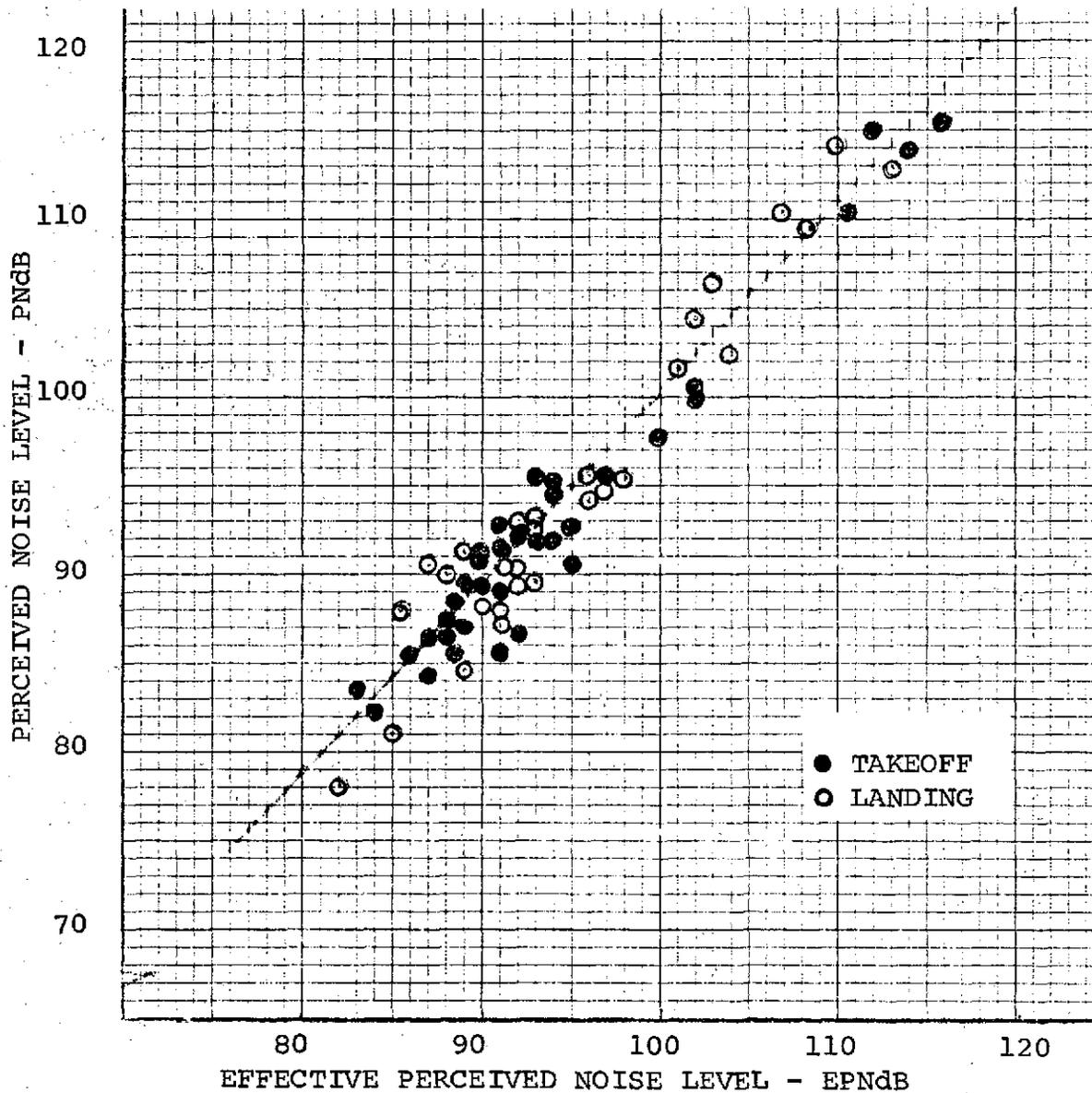


FIGURE 21. COMPARISON OF MODEL 347 PERCEIVED AND EFFECTIVE PERCEIVED NOISE LEVELS DURING TAKEOFF AND LANDING.

numerically equal, indicates that during takeoffs and landings, the time to the 10 PNdB down points is about 15 seconds. The actual maneuvers were conducted in a manner which represented efficient commercial operation.

Examination of Figures 15 through 20 reveals that the anticipated certification criteria are most closely approached by the shallower takeoff and landing trajectories (Figures 15 and 18). Community noise considerations, however, might include consideration of area within a given EPNdB level. Results reviewed in this manner reveal a less consistent pattern. For example, in comparing takeoffs illustrated in Figures 15 and 16 it appears that a larger area within the 90 EPNdB contour occurs during the shallow takeoff of Figure 15, but a larger area within 100 EPNdB arises from the steeper takeoff shown in Figure 16. In view of the inconsistency in applying the area concept, the noise reduction goals for the Model 347 helicopter will be based on meeting certification criteria. Therefore, in order to assess the relative contribution of various noise sources (rotors, engines, etc.), the data at each of the 25 grid points is shown in terms of noy values in Figures 22 and 23 for the conditions which most nearly meet certification criteria.

Since the noy value is the pressure and frequency sensitive component of the perceived noise level calculation, the frequency producing the largest noy value is the greatest contributor to the perceived noise.

Detailed analysis of narrow band spectra relate frequency in octave bands to aircraft noise sources as follows:

- 63 Hz: Rotor - Rotational Noise
- 125 Hz: Rotor - Rotational Noise and Bang, if it occurs
- 250 Hz: Rotor - Bang, if it occurs
- 500 Hz: Rotor - Bang, if it occurs
- 1000 Hz: Rotor - Bang, if it occurs, and engine noise
- 2000 Hz: Engine Noise
- 4000 Hz: Engine Noise
- 8000 Hz: Engine Noise

Unfortunately, the acoustical signature of the T55-L-11 gas turbine which powers the Model 347 helicopter has an extremely complex acoustical signature, which contains many pure tones which the engine manufacturers were unable to identify as to source. Thus, further subdivision into inlet noise, core noise, rotor-stator interaction, guide vane -

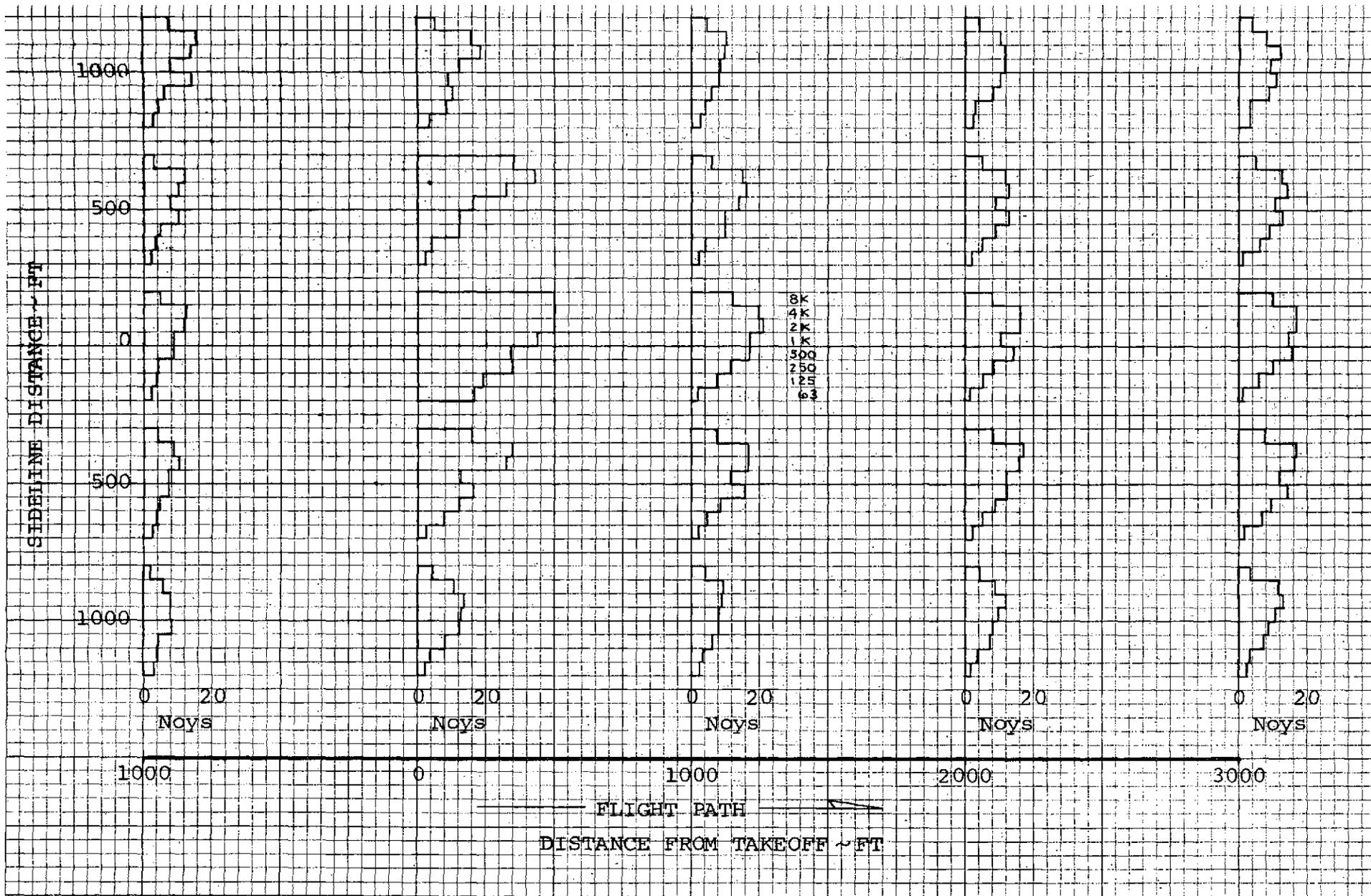


FIGURE 22. PERCEIVED NOISE WEIGHTING FACTORS (NOYS BY OCTAVE) - 10 DEGREE TAKEOFF

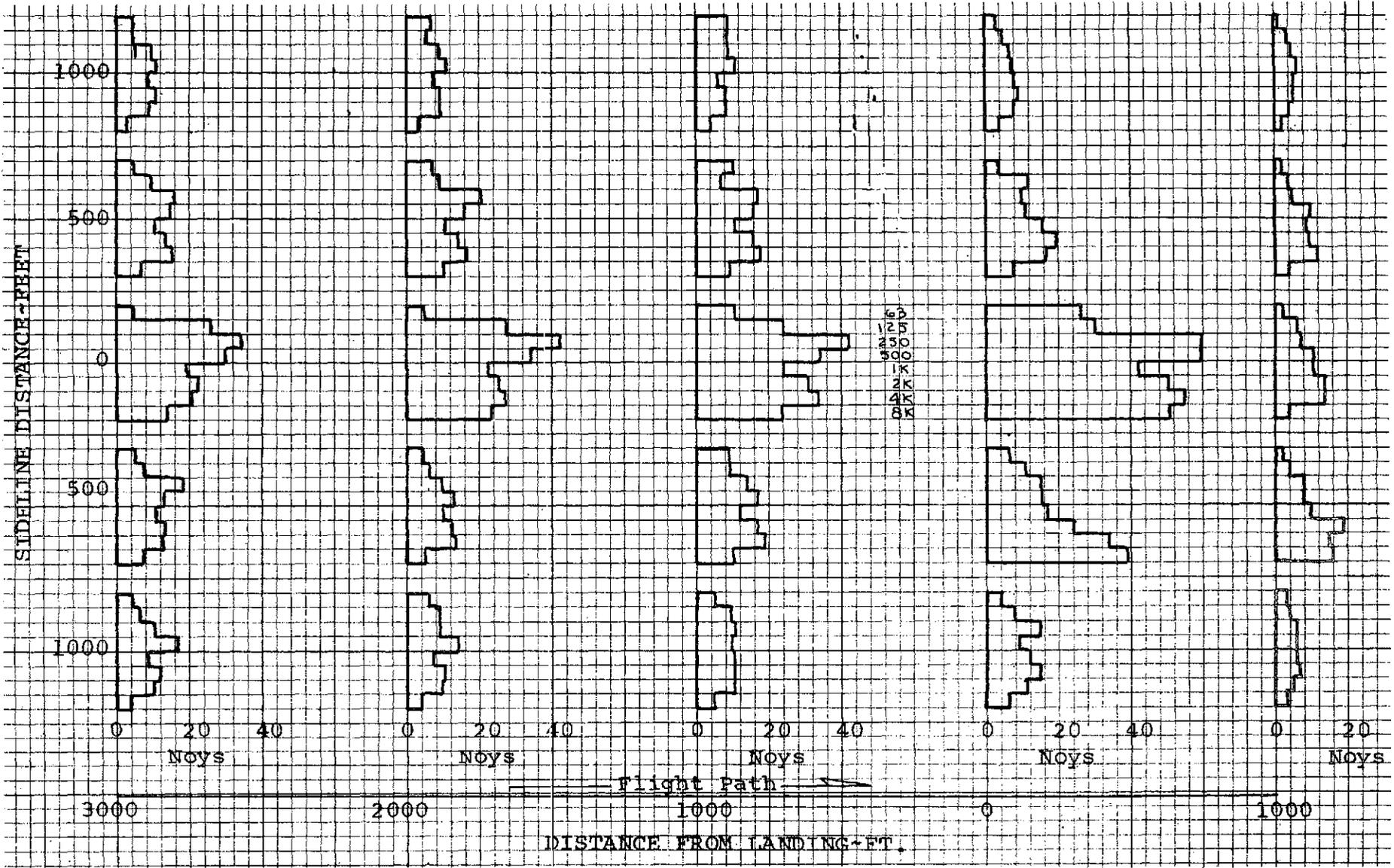


FIGURE 23. PERCEIVED NOISE WEIGHTING FACTORS (NOYS BY OCTAVE)- 10 DEGREE LANDING

rotor vortex interaction is not possible without further testing.

### Component Noise Reduction Requirements

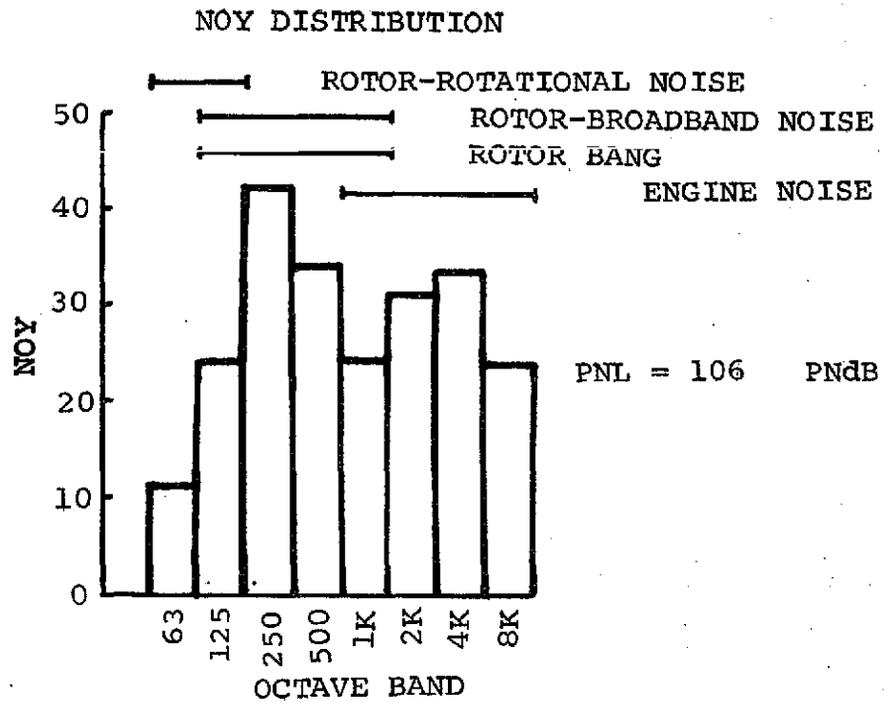
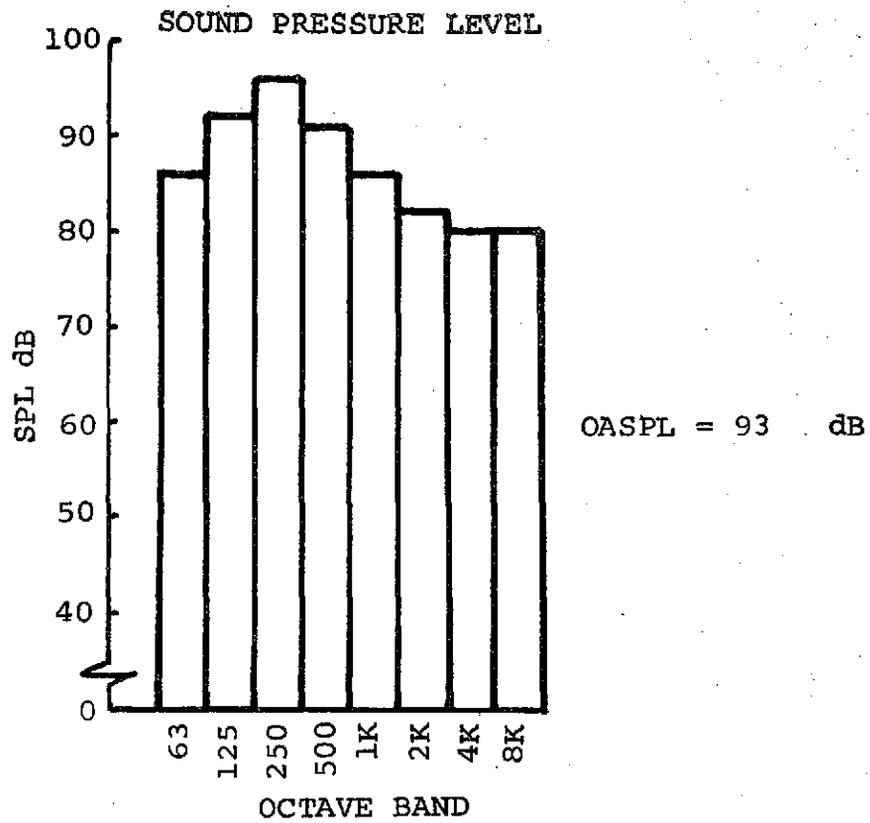
As can be seen from Figures 15 and 18, the most critical location with regard to meeting certification criteria is during landing (Figure 18), directly under the flight path 1000 feet behind the touchdown point. The corresponding noy bar chart from Figure 23 is shown in larger scale in Figure 24, along with the actual sound pressure level distribution. Examination of this figure clearly indicates that reduction of both rotor and engine noise is required to meet the target of 95 PNdB.

Reduction of rotor noise (Figure 25) involves elimination of blade bang and further reduction of rotational and broad-band components. The assumed reductions are based on a review of extensive Boeing Vertol test data, and discussed in greater detail in the section dealing with Component Noise Reduction Approaches.

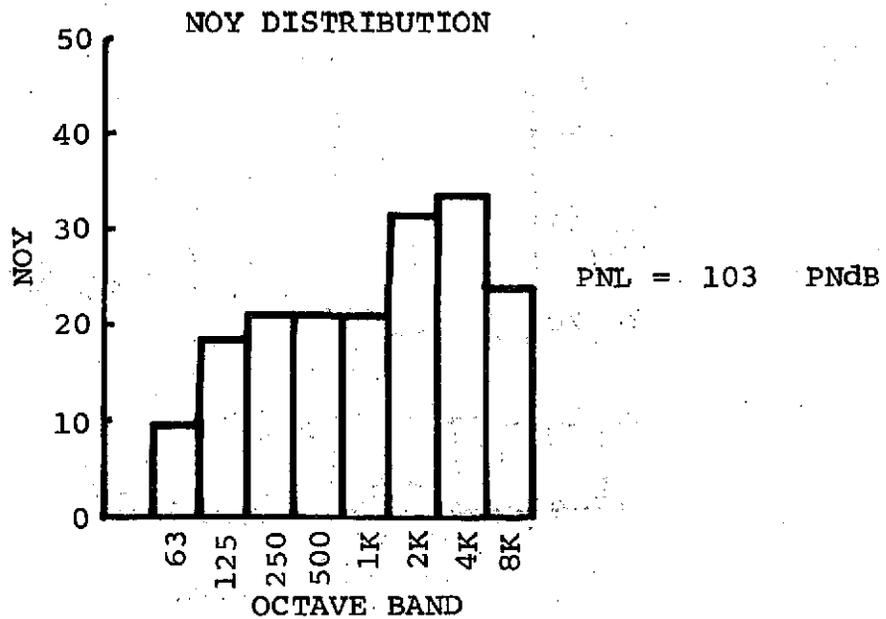
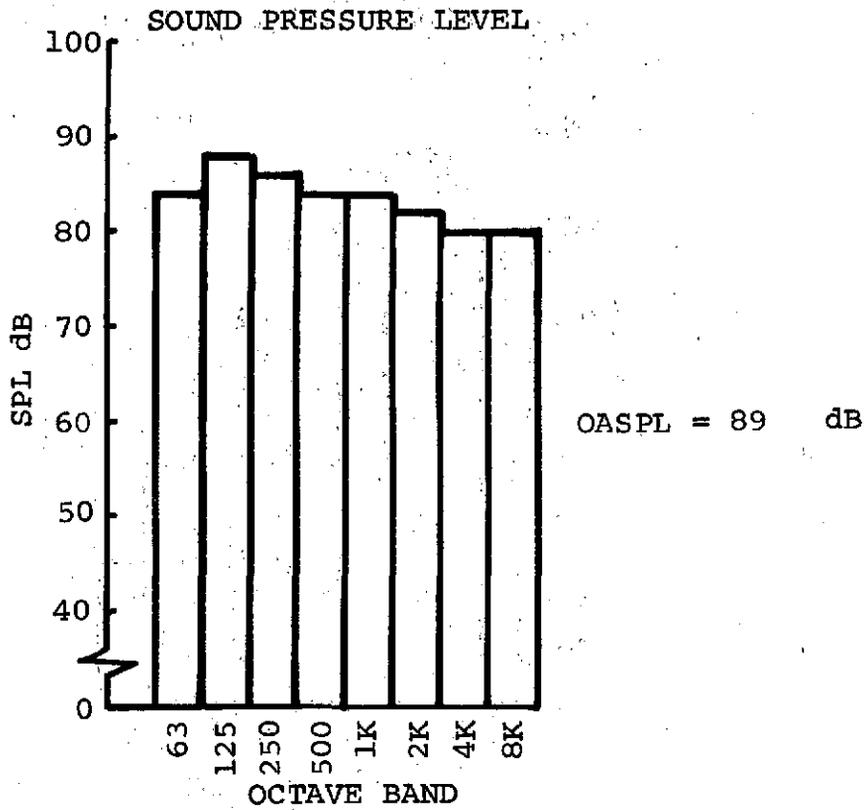
In order to meet the final objective, it is also required that engine system noise be reduced. In this case (Figure 26), the reduction has been assumed to be the amount, which when combined with rotor noise reduction, will meet the 95 EPNdB criteria.

After achieving the above reductions it is conceivable that lower level sources from dynamic components, accessories, etc., which have not been revealed by data of the current configuration, may become important. It can be safely assumed, however, that reduction of noise from sources inside the fuselage can be achieved, if required, by application of well established noise control methods which will not require research programs.

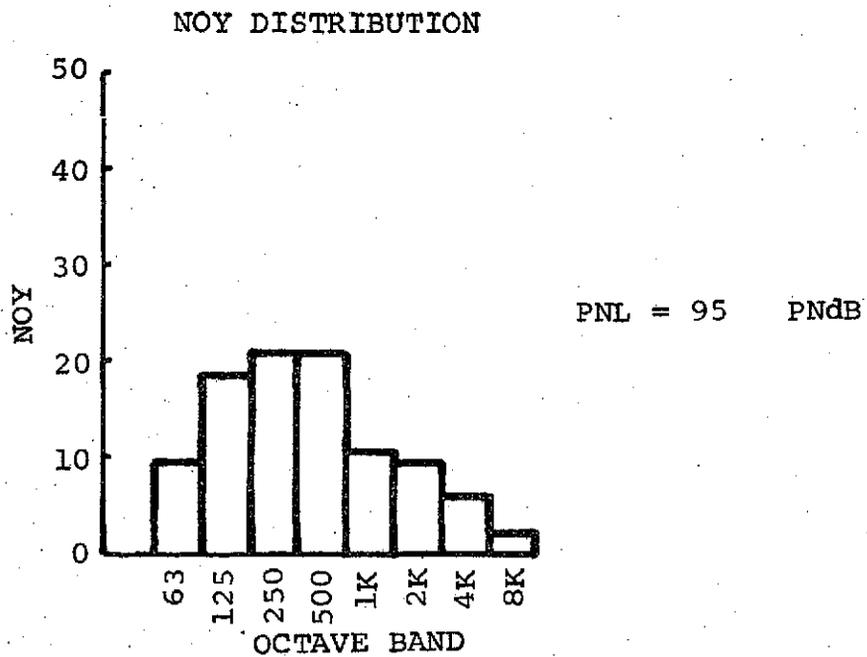
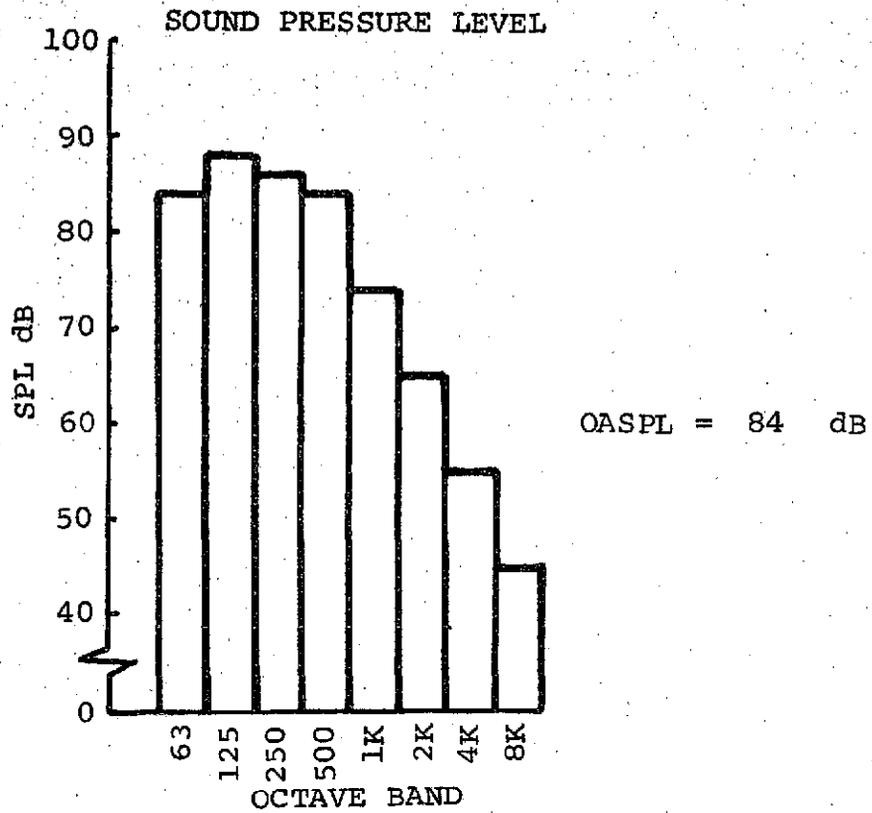
Achievement of the required limit at the "critical point" studied, will also ensure compliance at the other measuring points during takeoff, or landing. Figures 27 and 28 show the anticipated footprints which were calculated based on the predicted noise reductions, assuming no major change in directivity.



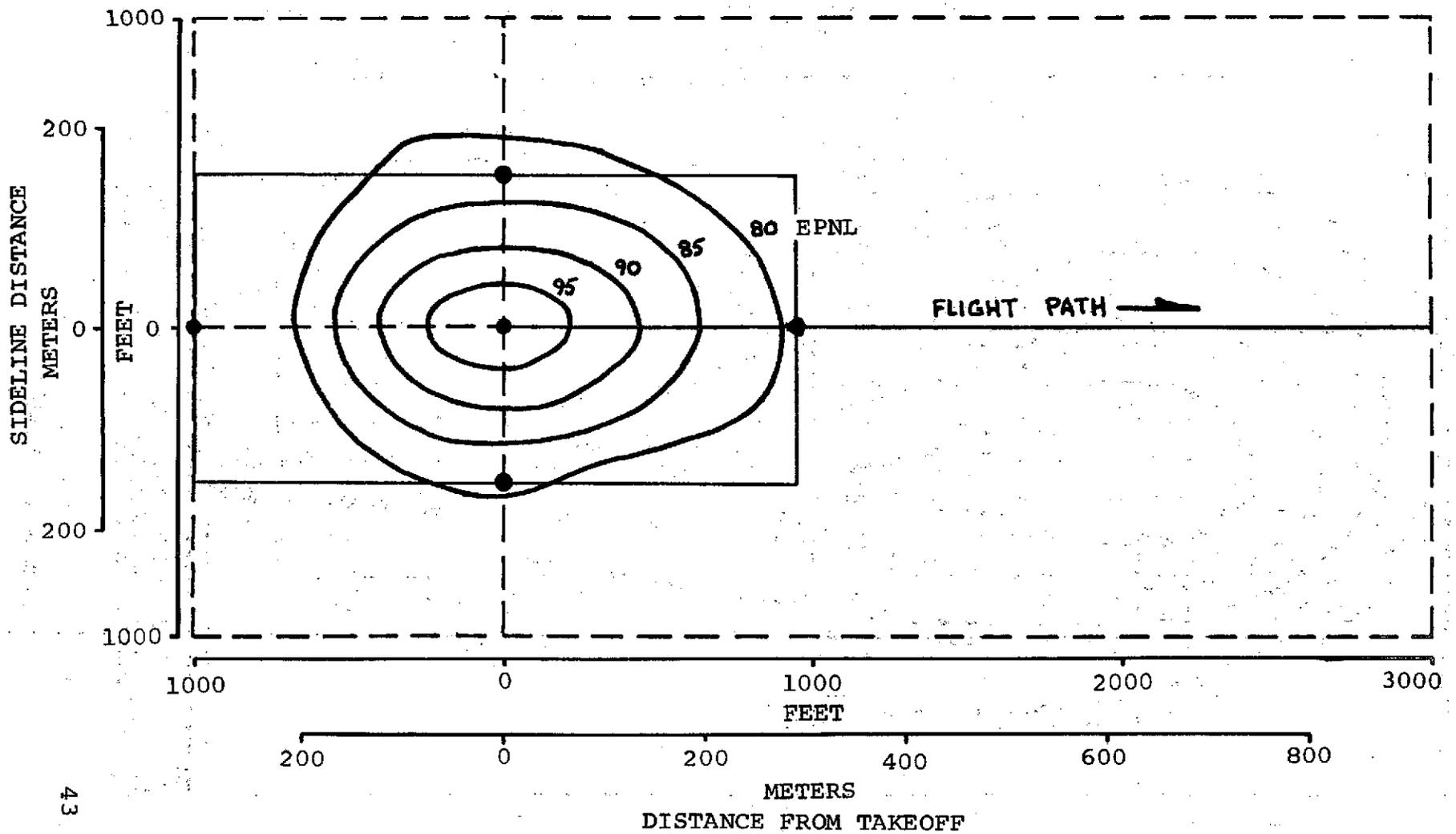
**FIGURE 24 DETAILED NOISE DISTRIBUTIONS FOR MOST CRITICAL CERTIFICATION POINT - UNMODIFIED AIRCRAFT**



**FIGURE 25 DETAILED NOISE DISTRIBUTIONS FOR MOST CRITICAL CERTIFICATION POINT - MODIFIED ROTOR BLADES**



**FIGURE 26 DETAILED NOISE DISTRIBUTIONS FOR MOST CRITICAL CERTIFICATION POINT - MODIFIED ROTOR BLADES AND ENGINES**



43

FIGURE 27. MODIFIED MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
 VERTICAL TO 120' - 10 DEGREE CLIMB

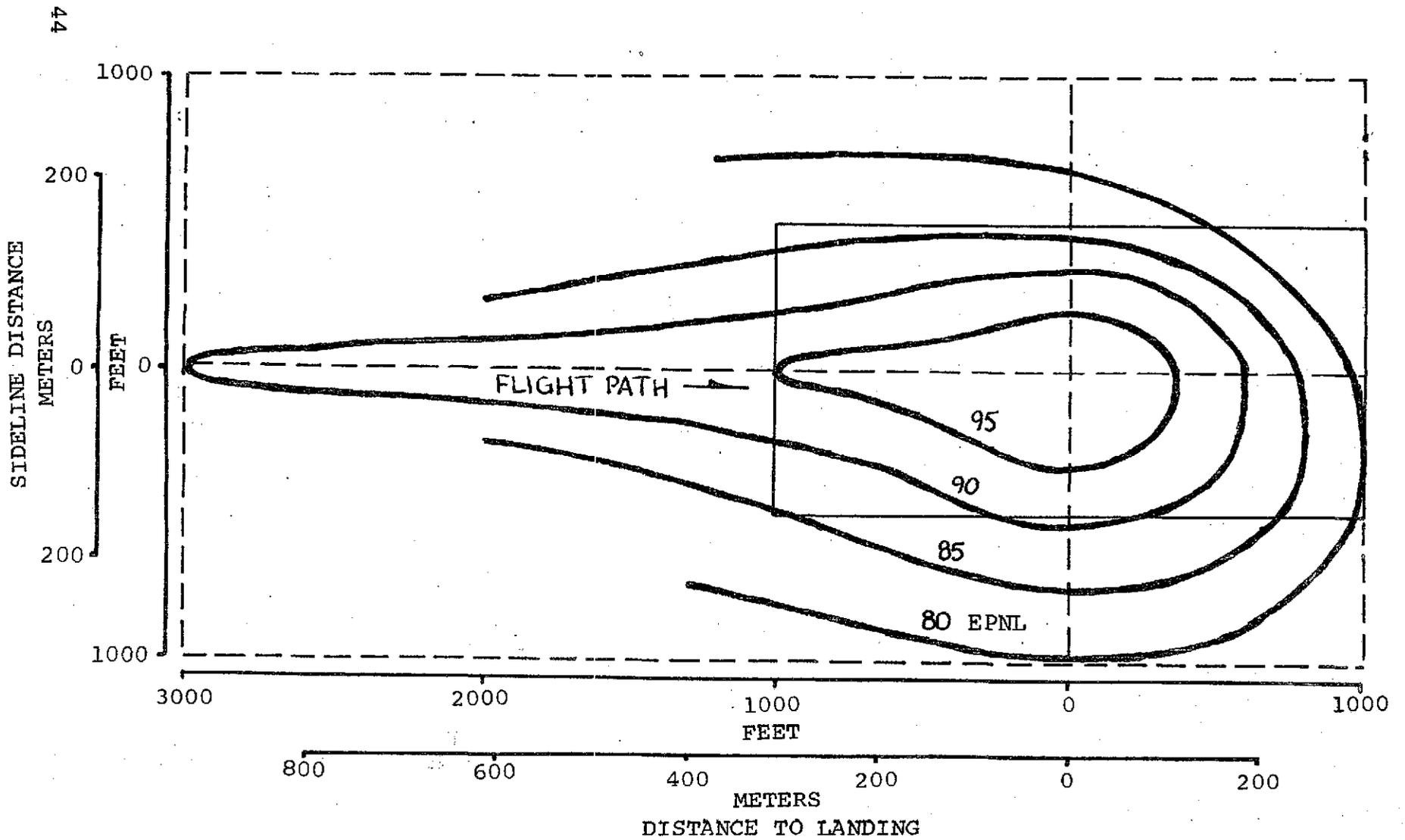


FIGURE 28. MODIFIED MODEL 347 EFFECTIVE PERCEIVED NOISE LEVEL CONTOURS (EPNL)  
10 DEGREE APPROACH

## Component Noise Reduction Approaches

### Analytical Methods and Experimental Data. -

**Rotor Noise:** A prominent rotor noise source on overlapped tandem rotor helicopters may be due to rotor-rotor interaction. This may take form in either of two ways. First, the vortex shed from a rotor blade on, for example, the front rotor may be intersected by the next blade, which is part of the aft rotor system. Depending on rotor control settings, or flight conditions, the converse may also happen: a front rotor blade intersects a vortex shed by a rear rotor blade. In either case, a sharp acoustic pulse is produced with directional properties governed by the angle and speed of intersection. Figure 29 illustrates the type of acoustic event produced, commonly called blade "bang", in terms of its pressure-time history and spectral content. The second type of rotor-rotor interaction on overlapped tandem helicopters is due to the downwash in the overlap area. Less is known about the noise effects of the downwash impinging on a rotor system than of the blade-vortex effects. However, some experimental investigations performed by Boeing Vertol on an overlapping model tandem rotor system indicate that even with a blade spacing mid-way between shed vortices, resulting in minimum noise generation, a spike, or banging waveform, results from the overlapped downwash effect (see Figure 30). A separate indication of this effect was confirmed by dissipating the shed vortex completely (by means of a tip mounted spoiler and observed by means of smoke visualization techniques). Figure 31 shows the reduction achieved by dissipating the vortex, yet a bang signature remains as indicated by the downward spikes in part b. of the figure. When the downwash effects, due to overlap, are completely removed (as shown in part c. of Figure 31), a non-banging acoustic signature results. Indications are that the downwash effect results in an acoustic pulse, which is less severe than that produced by blade-vortex interaction and that downwash effects, together with rotor rotating direction are basically responsible for the asymmetric far-field noise pattern of the tandem rotor helicopter.

The problem of blade-vortex interaction was largely eliminated on the Model 347 by additional blade separation achieved by increasing aft pylon height, and lengthening the fuselage. However, at low speeds and in hover an impulsive signature remains which requires further treatment.

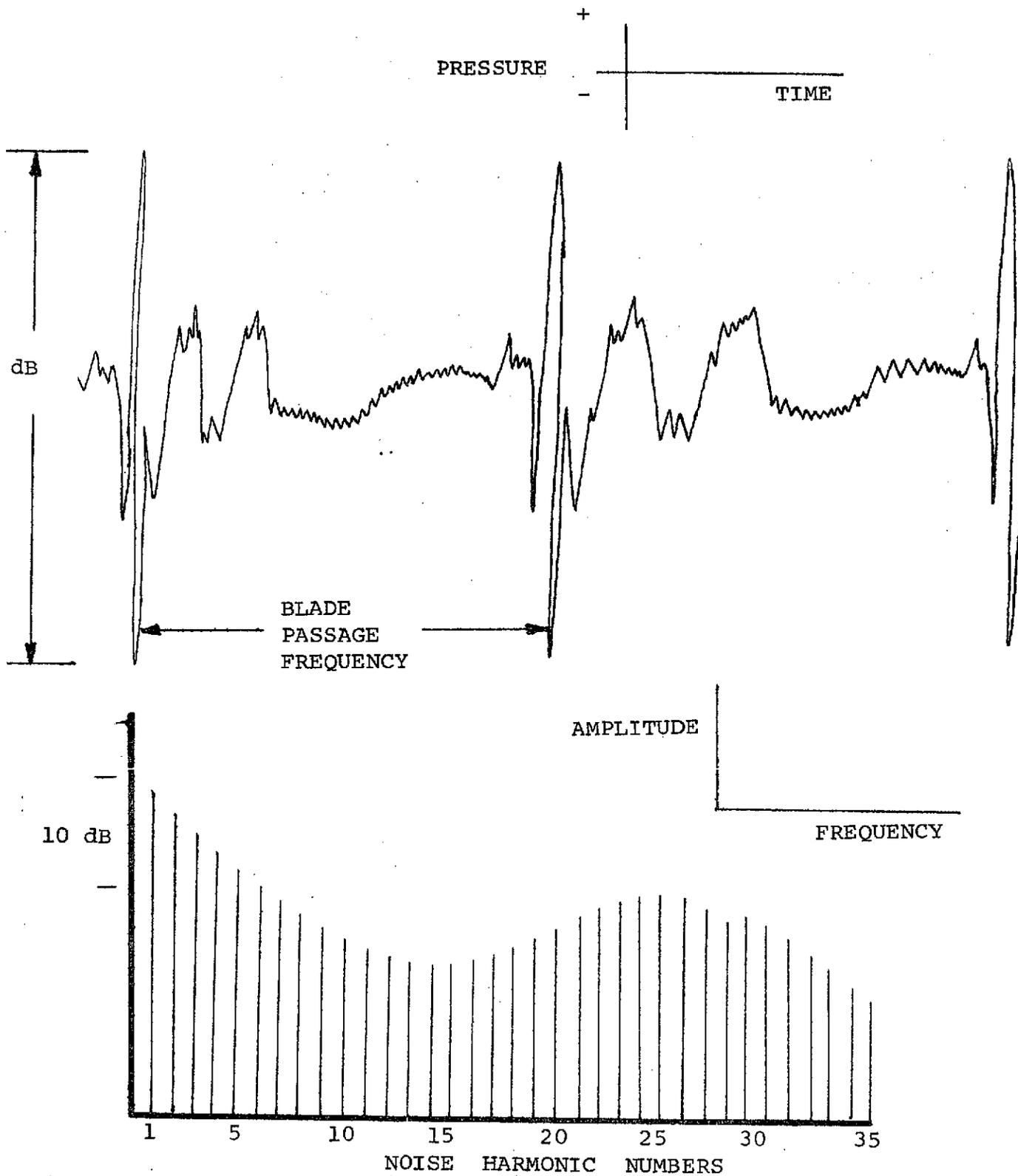
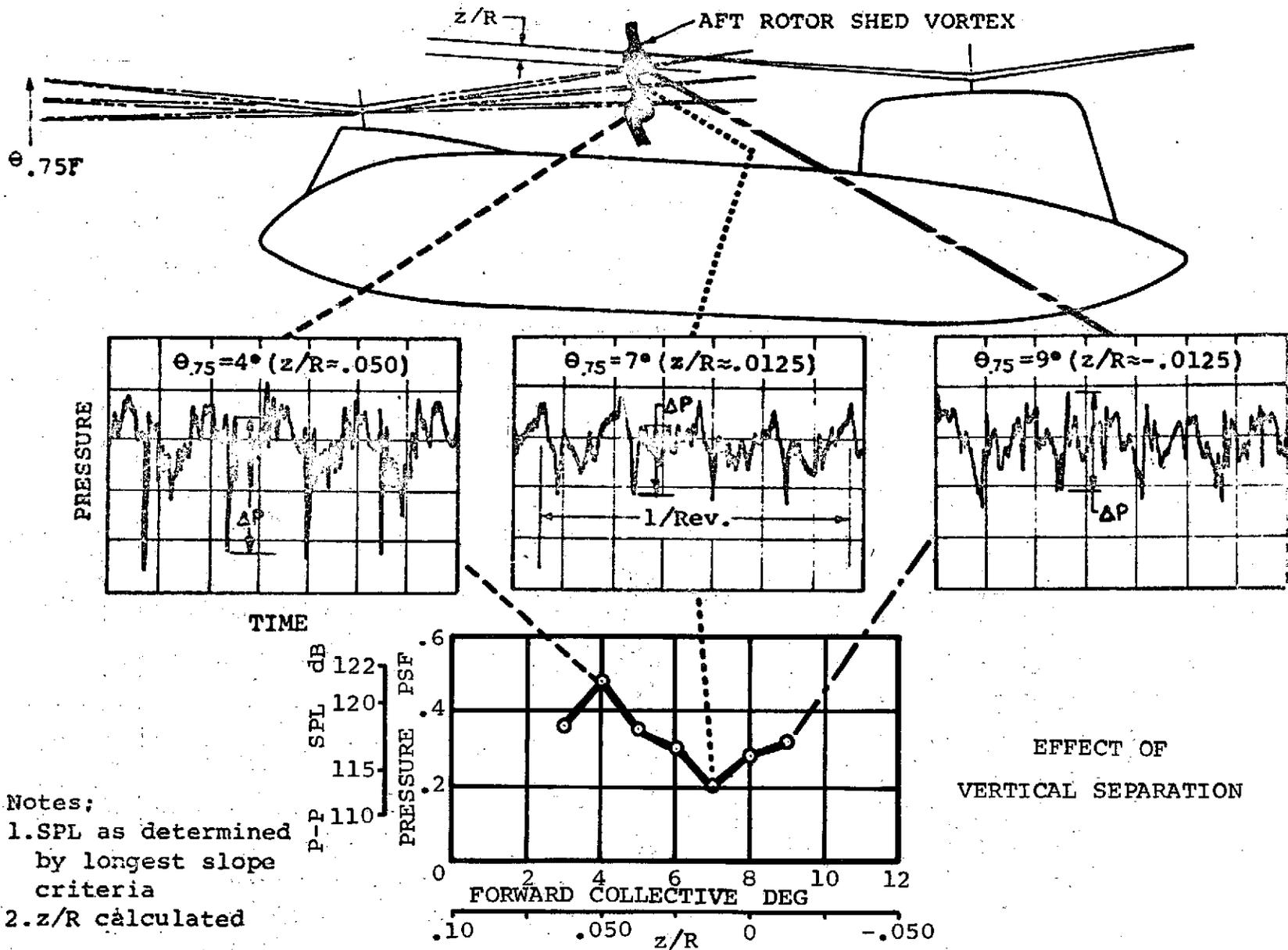


FIGURE 29. BLADE "BANG" SIGNATURE

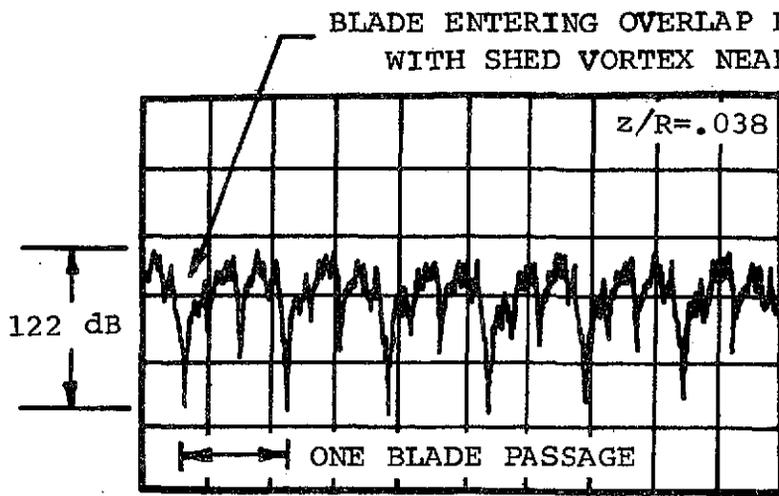


Notes:  
 1. SPL as determined by longest slope criteria  
 2.  $z/R$  calculated

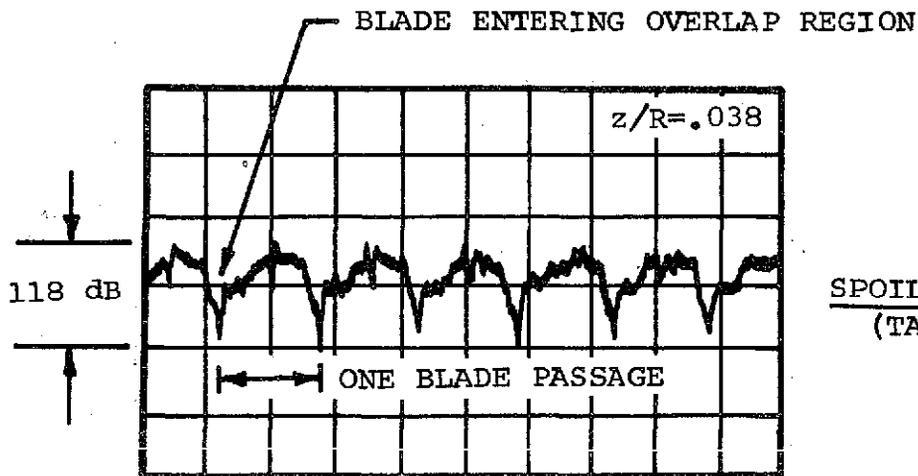
47

FIGURE 30. EFFECT OF BLADE - VORTEX SPACING ON ROTOR NOISE

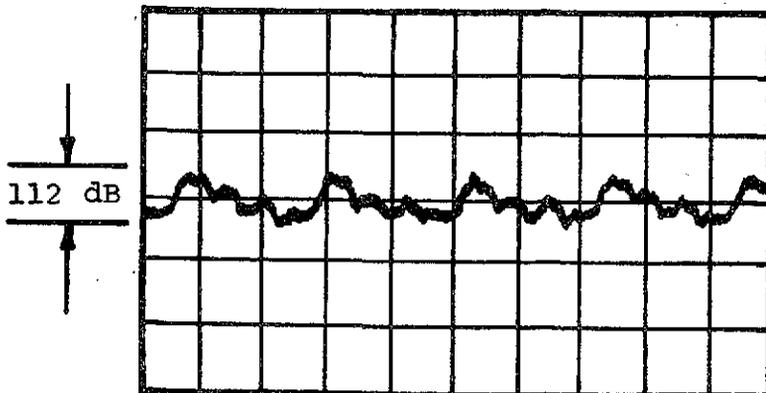
UHM MODEL DATA



a.  
SQUARE TIP CONFIG.  
(TANDEM HEL.)



b.  
SPOILER TIP CONFIG.  
(TANDEM HEL.)



c.  
SQUARE TIP  
(ISOLATED ROTOR)

FIGURE 31 EFFECT OF ROTOR-VORTEX INTERACTION ON ACOUSTIC WAVEFORMS

In the past fifteen years, much effort has been concentrated on modifying the strength and size of the shed vortex by means of blade tip shape modifications. Figure 32 illustrates various concepts tested on scale model tandem rotors, several of which have also been flight tested.

Data indicates that the use of blade tip modifications can have little effect on the vortex structure, and therefore are relatively ineffective in reducing noise due to blade vortex intersections.

Since rotor modifications have not appeared promising, the approach to complete elimination of tandem bang in all flight regimes lies in further physical rotor separation. This is clearly demonstrated by the flight test data shown in Figure 33. The separation on the CH-47 and CH-46 helicopters was achieved by cyclic trim while the separation on the Model 347 was achieved by pylon height. The latter is preferable, since extreme cyclic trim settings can involve excessive fuselage attitudes resulting in poor performance, and unacceptable pilot visibility. Figure 33 also illustrates the amount of noise reduction achieved for less overlap.

These results have been achieved at all airspeeds with the exception of transition and hover. Pylon height and cyclic trim methods also do not control the amount of noise due to rotor-rotor downwash interference effects. Both vortex and downwash effects can be minimized in most flight regimes, and all airspeeds by eliminating the aerodynamic overlap entirely. A noise control concept is proposed as a modification to the existing Model 347 helicopter fuselage by lengthening the cabin section by an additional 90 inches. This is expected to eliminate rotor bang including in hover, with a resultant decrease primarily in the 250 and 500 Hz octave band sound pressure levels. This will help in achieving lower levels required to meet certification criteria, and will be more subjectively acceptable from the communities' point of view than PNdB or dBA measures would indicate.

In addition to rotor-rotor and rotor-vortex interaction, an isolated single rotor is subject to constraints imposed because of possible single rotor "bang" generation. This occurs whether the rotor is the main rotor of a single rotor helicopter, or one of a pair of non-interacting rotors of a tandem helicopter configuration. The concept has been

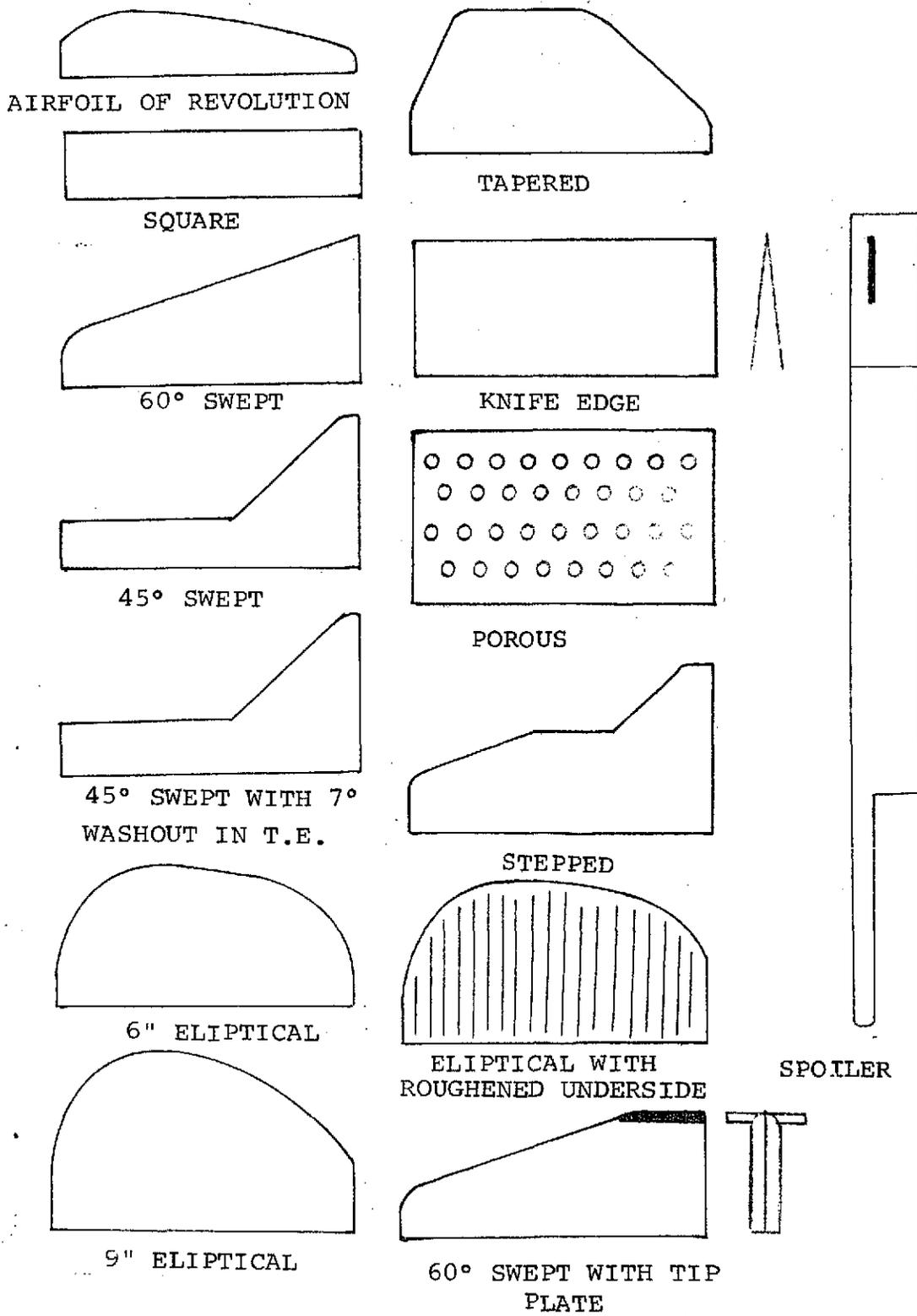


FIGURE 32. BLADE TIP CONCEPTS

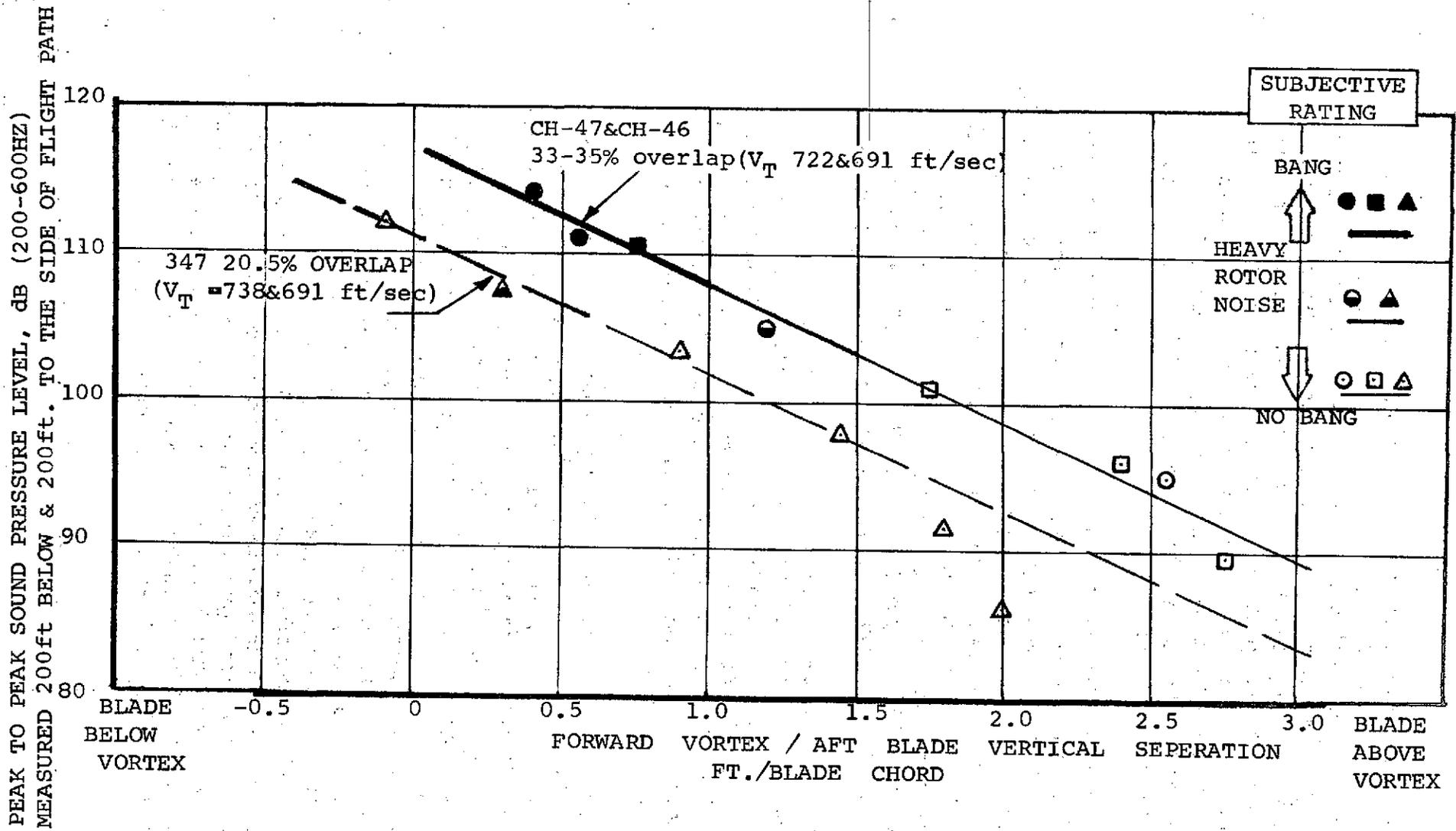


FIGURE 33 EFFECT OF BLADE-VORTEX SEPERATION ON

researched on the Boeing Vertol rotor test tower, and this phenomenon is illustrated in Figure 34, and described in detail in Reference 7. When a blade is operating above the shock boundary, it appears that a sharp noise arises, and can be triggered by any disturbance, such as wind gusts, control inputs, or vortices shed from preceding blades. The control over this noise lies in the development, and selection of airfoils having an adequate shock boundary limit. Figure 35 shows, for example, the wide latitude of limits which can be achieved by airfoil selection.

An additional noise constraint imposed on the helicopter, (illustrated in Figure 36) stems from high advancing blade tip speed operations. The source of this disturbance is rotor drag divergence at high local blade Mach numbers which is a function of local flow velocity, and therefore airfoil shape. Acoustically, the phenomenon manifests itself as a pulse sounding very similar to tandem rotor-vortex interaction (Reference Figure 29). For a Vertol V23010-1.58 airfoil, the basic noise limiting characteristics are shown in Figure 37.

Modifying the outer 10 to 20 percent radius of a rotor blade's shape can be an effective way to delay the onset of high speed bang, as Mach number is increased. Considerable model and full scale flight testing has been conducted and is in progress on such noise control tactics. The following paragraphs describe two such blade tip concepts, and the acoustic results achieved.

One concept for reducing high tip speed bang is illustrated in Figure 38. Wind tunnel model tests have been performed comparing the acoustic characteristics of both a standard 0012 blade from blade root to tip, (referred to as the thick tip), and the 6 percent thickness airfoil tip section called the thin tip. The rotating model rotor was operated at several tip speeds in varying tunnel flow velocities to simulate full scale operational rotor rpm's, and advance ratios of a typical helicopter. Figure 39 illustrates the basic test results achieved. Both impulse noise, from advancing blade tip bang, and basic rotational noise, were reduced in the range of advancing tip Mach numbers of about 0.8 to 0.9. Subjective aural evaluations were then made of both rotor blade tip configurations using psychoacoustic test methods with results as illustrated in Figure 40. These results were achieved by suitable frequency scaling of model test data to simulate full scale rotor waveforms, and

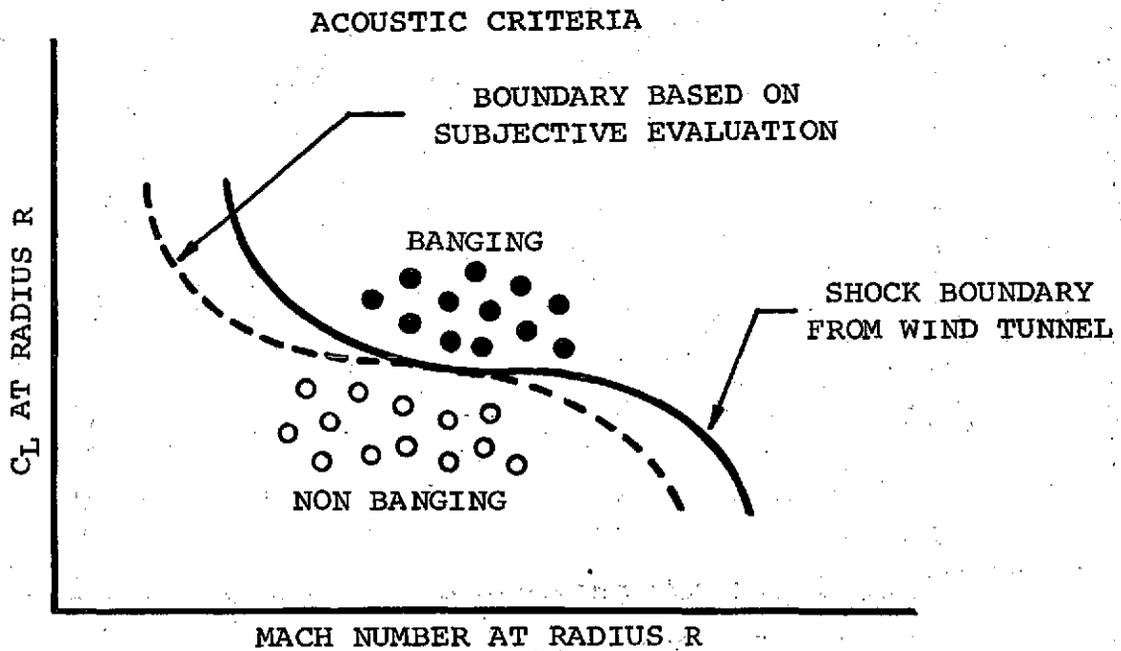
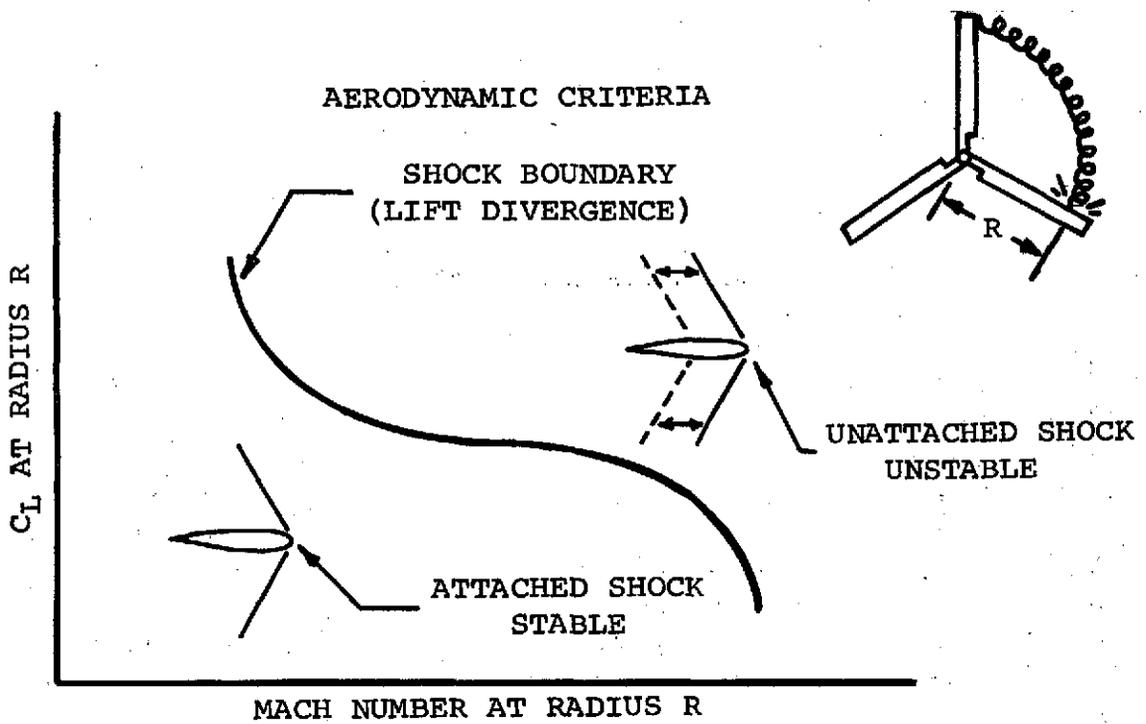


FIG. 34. SINGLE ROTOR HOVER IMPULSIVE NOISE CRITERIA

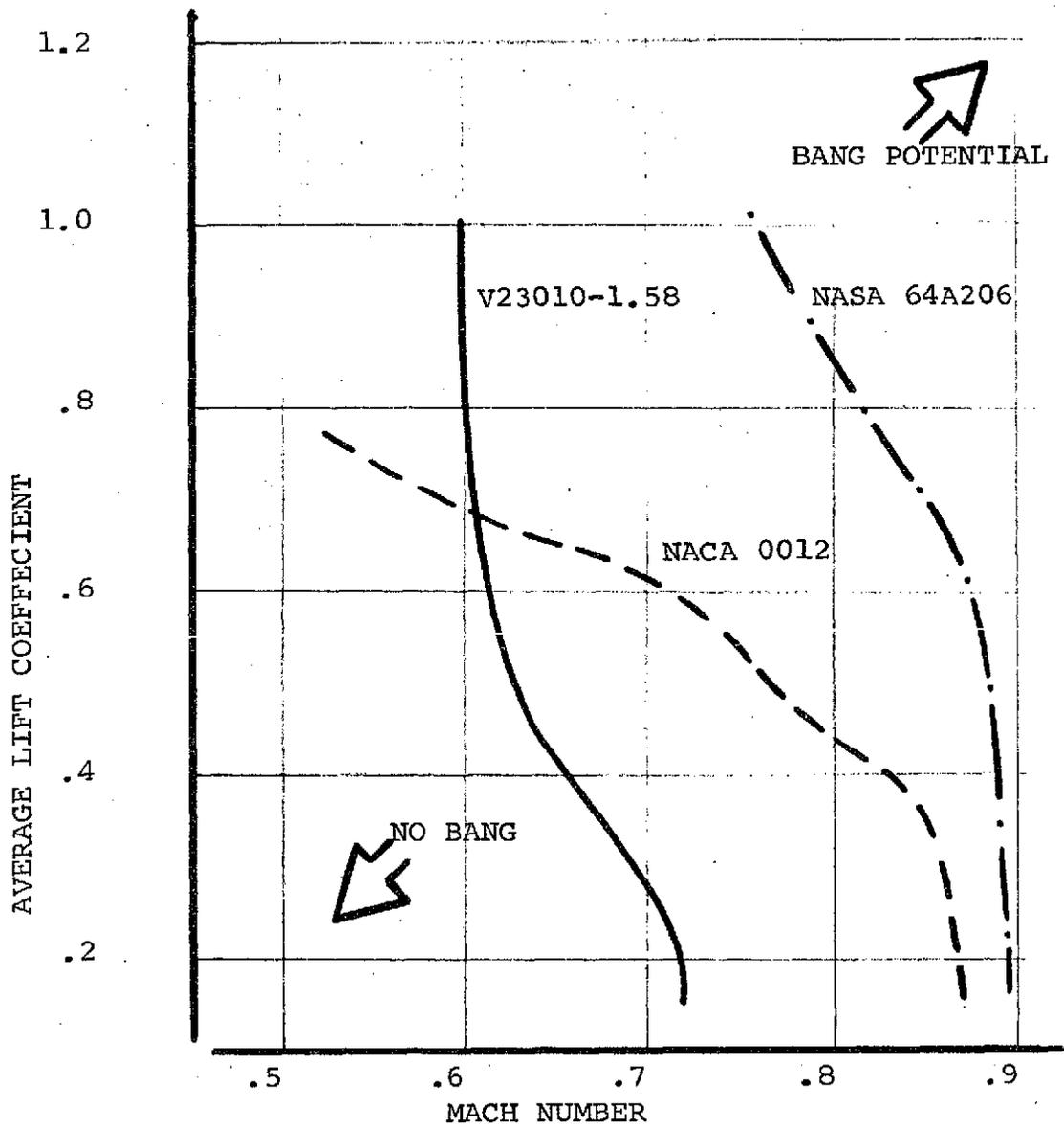


FIGURE 35: LIFT DIVERGENCE BOUNDARIES FOR SEVERAL AIRFOIL SECTIONS

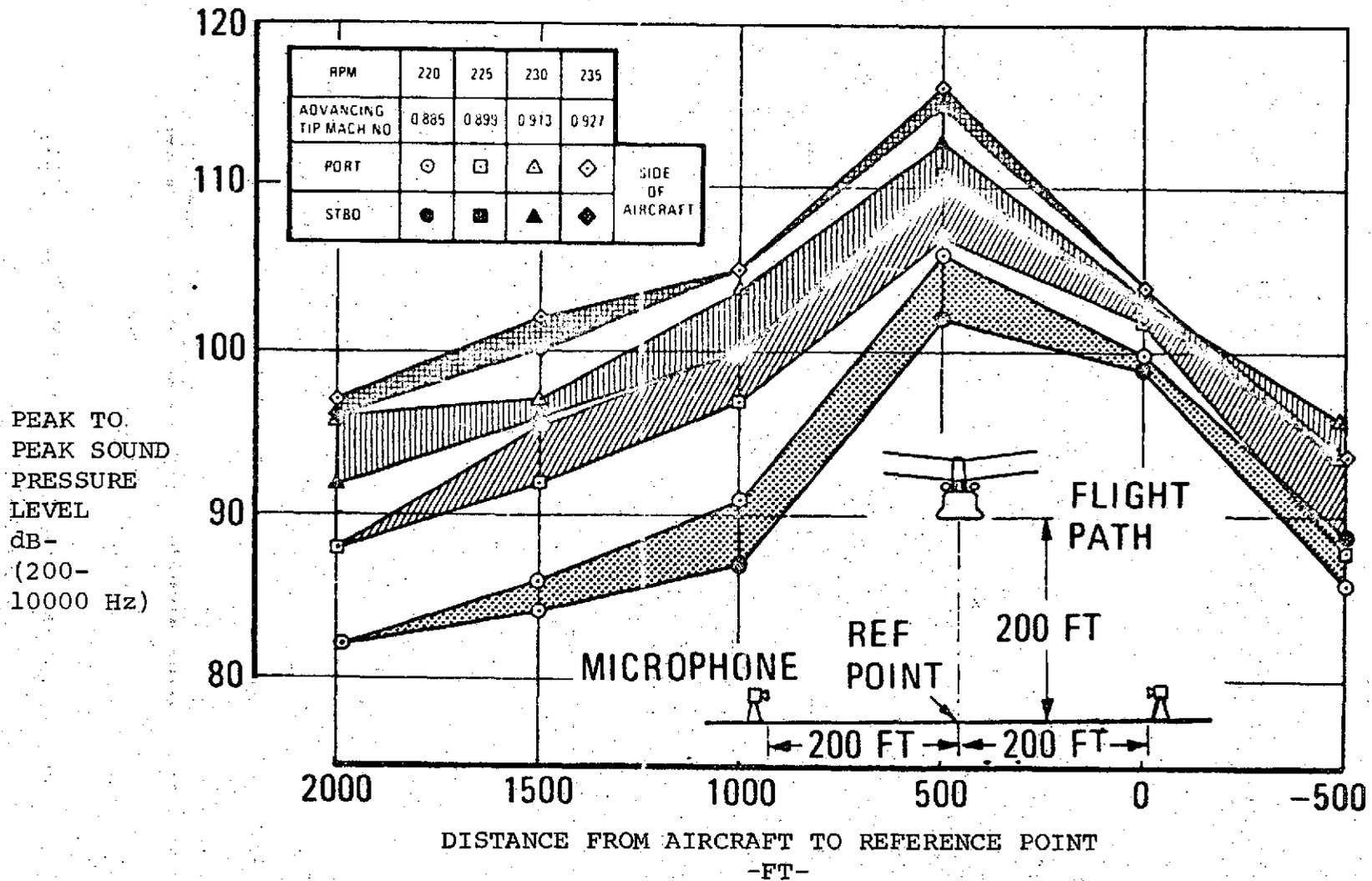


FIGURE 36 MODEL 347 FLYBY NOISE - 170 KNOT TRUE AIRSPEED

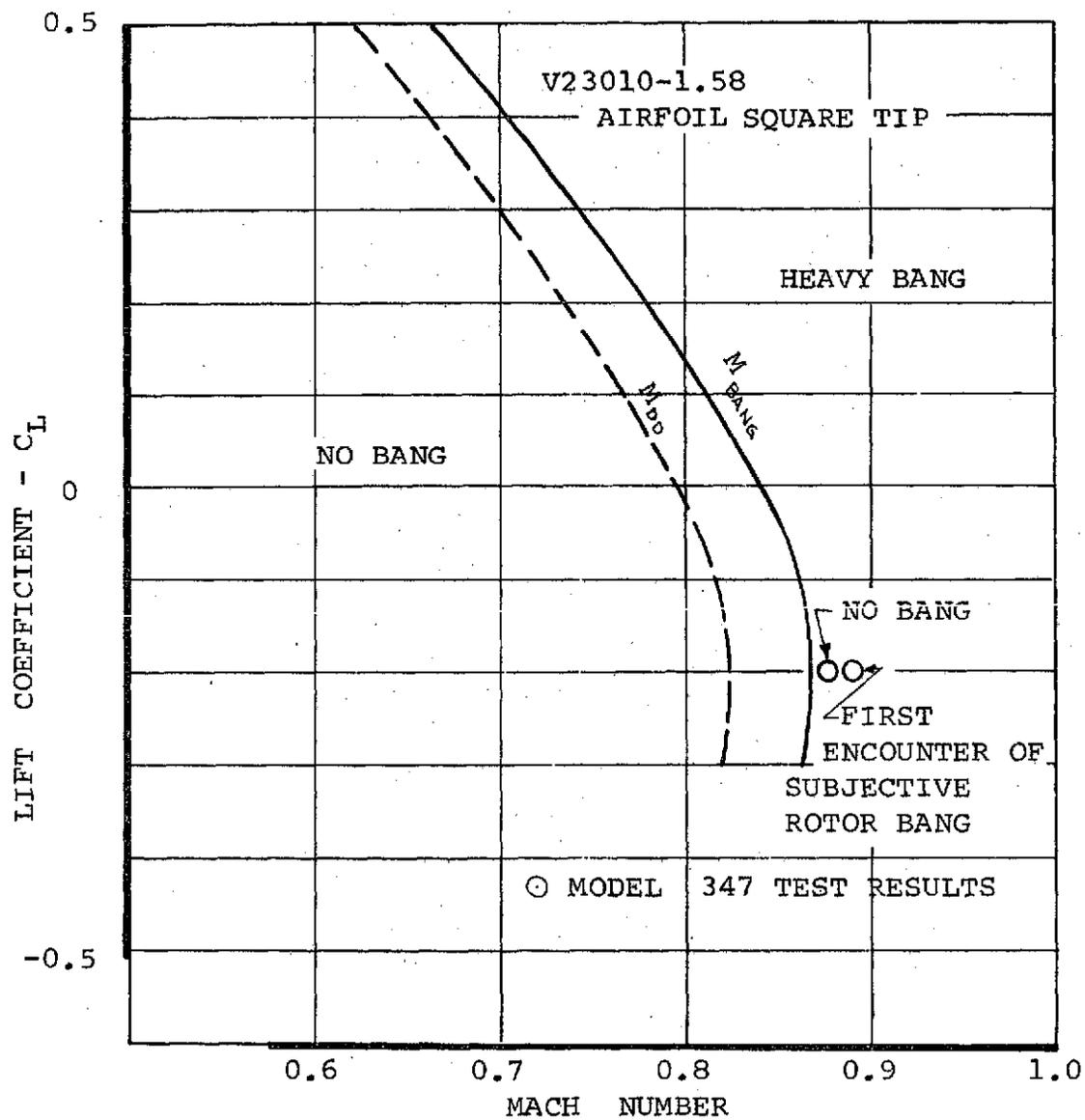


FIGURE 37 SINGLE ROTOR BANG CRUISE NOISE LIMITS

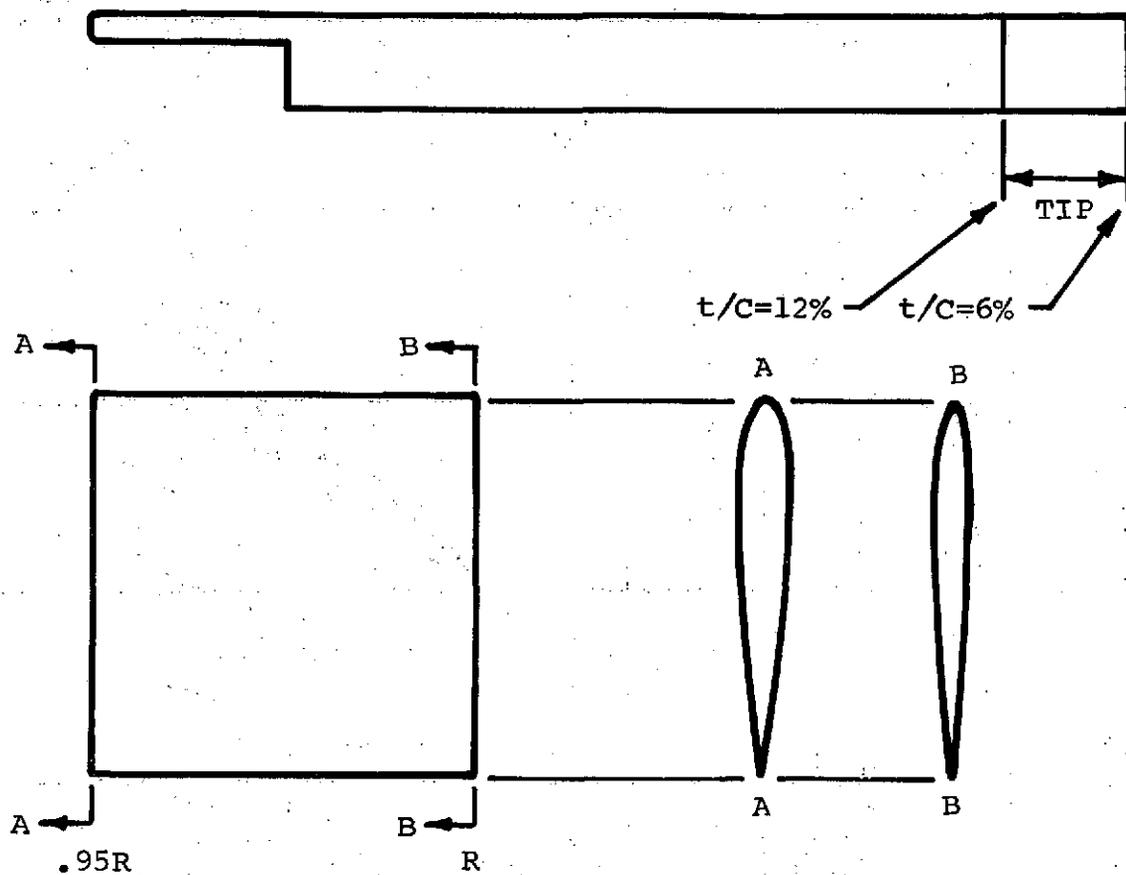


FIGURE 38 THIN TIP CONCEPT

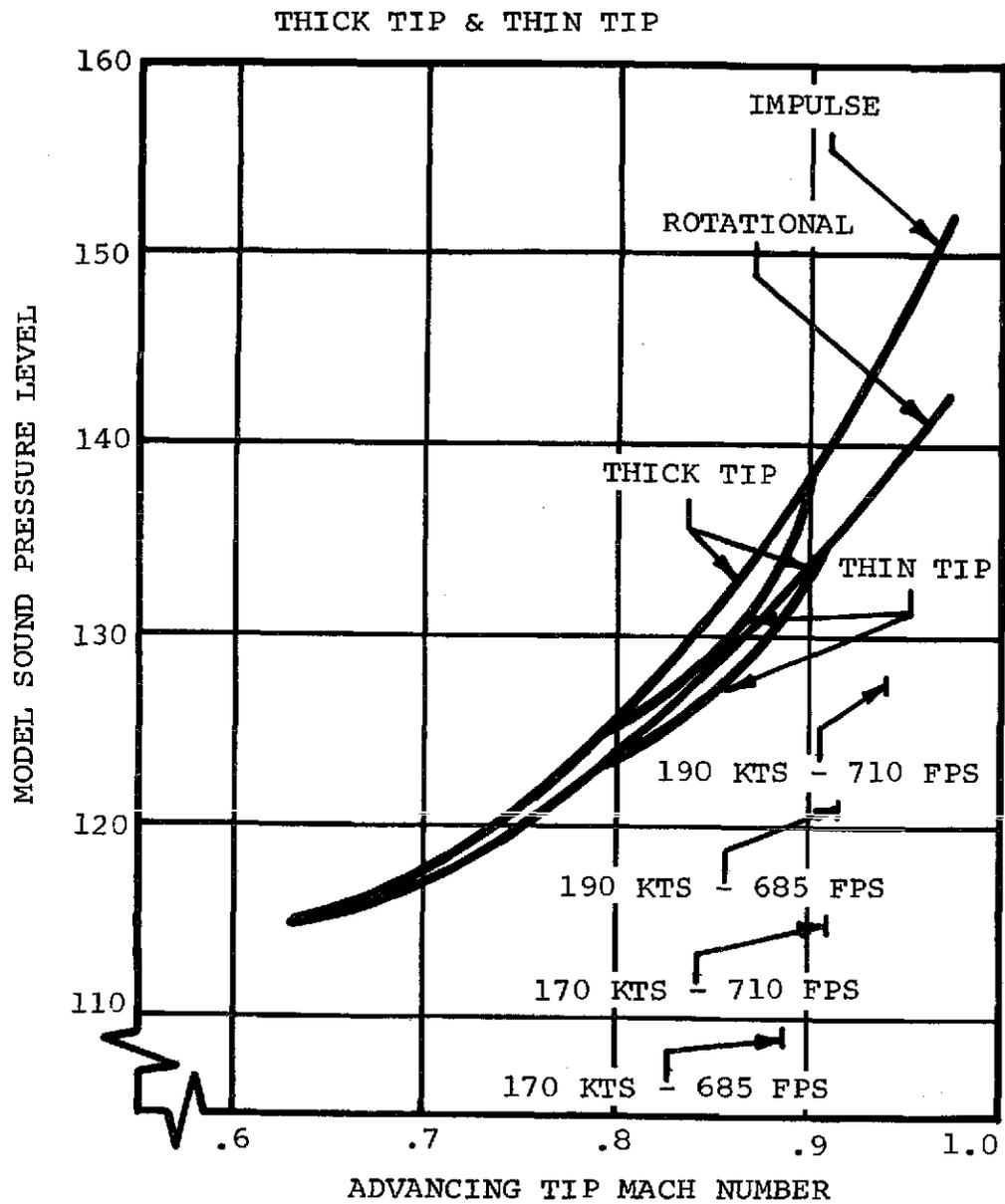


FIGURE 39 THIN TIP - NOISE TEST RESULTS

RESULTS OF SUBJECTIVE TEST

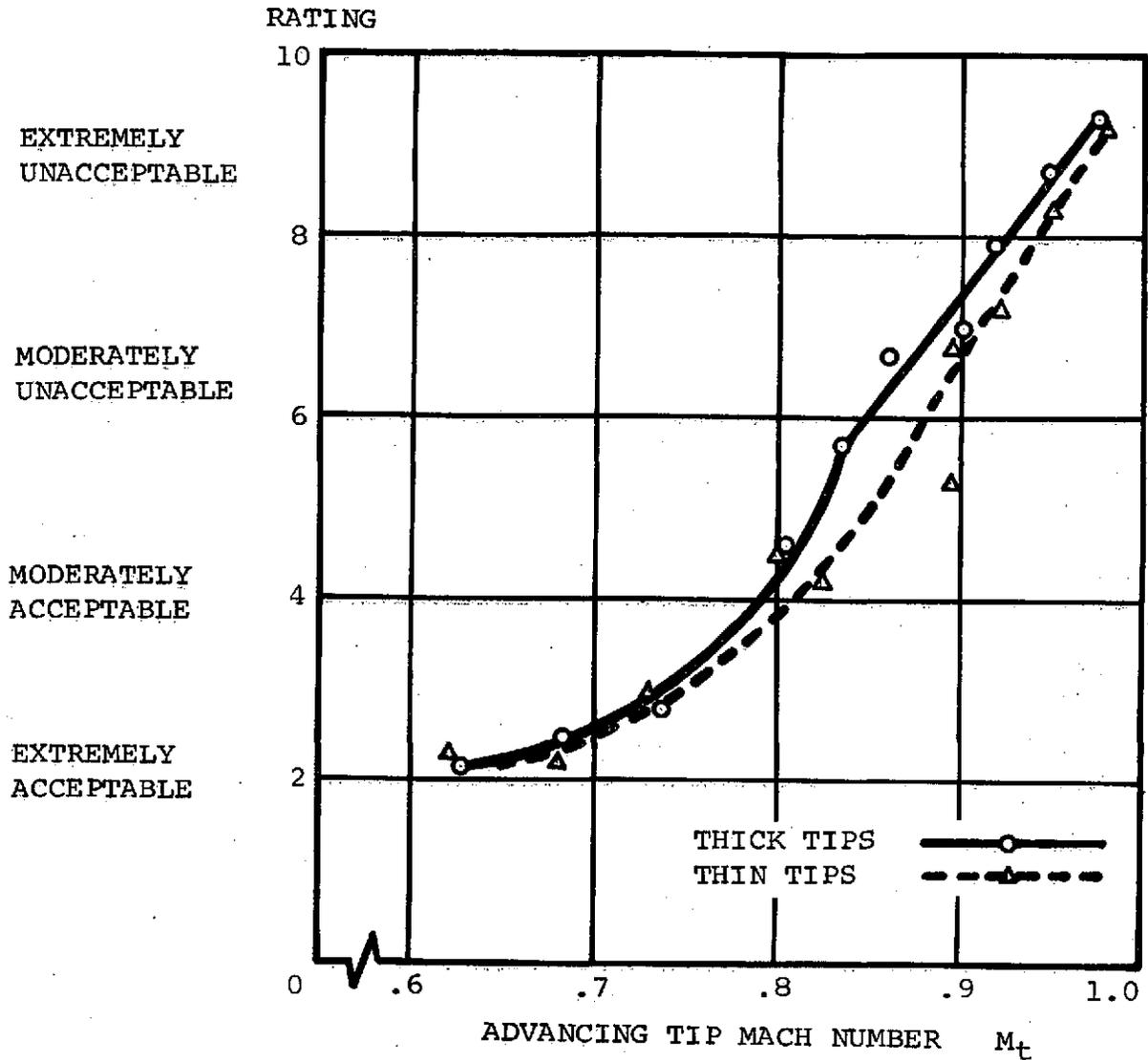


FIGURE 40 THIN TIP - PSYCHOACOUSTIC TEST RESULTS

spectra. The benefit derived by using a thin rotor tip is clearly discernible. The effect which this benefit is expected to have on the Model 347 helicopter cruise limit is illustrated in Figure 41 for two operating tip speeds. In each case, the single rotor bang noise limit has been extended by approximately 25 knots.

A second concept given serious consideration for the alleviation, or delay of onset of high tip speed bang is called the double swept tip (Figure 42). Considerable data is available on this concept since it was tested full scale on the Model 347 helicopter. Measured acoustic test data indicates objectively, the benefit with double swept tips over standard (0012) blades is about the same as the thin tip, about 0.02M increase allowable in advancing tip Mach number (Figure 43). Subjectively, however, the double swept tip increased the allowable advancing tip Mach number by 0.02M (13 knots) as compared to 0.04M (25 knots) for the thin tip (Figure 44).

The above test results indicates the thin tip is a better choice for alleviating high speed rotor blade bang than the double swept tip concept. Development of tip shapes which will further open the acceptable noise envelope appears promising.

Calculations show that over the limited range of operating rotor speeds in hover, a Model 347 helicopter rotor rpm change from 220 to 208 rpm is expected to reduce rotational noise by an average of only one decibel with unchanged perceived noise levels. Measurements indicate variations achieved around the azimuth of plus or minus three PNdB (see Figure 45). At 120 knots, however, the 208 rpm rotational noise levels are significantly lower in amplitude in the 31.5 Hz to 125 Hz octave bands, ranging from four to six decibels. This change in measurable noise level is clearly subjectively audible, yet if strict adherence to perceived noise calculations is followed, no significant PNdB reduction is credited. A discrepancy therefore exists between the PNdB analytical rating method used to indicate helicopter annoyance, and the subjectively perceived change in rotor noise. Therefore, although no demonstratable beneficial effects in terms of calculated perceived noise level warrant rotor rpm reduction to meet anticipated federal certification standards, a measurable and subjectively quite audible change has been effected impacting on the probable degree of community accept-

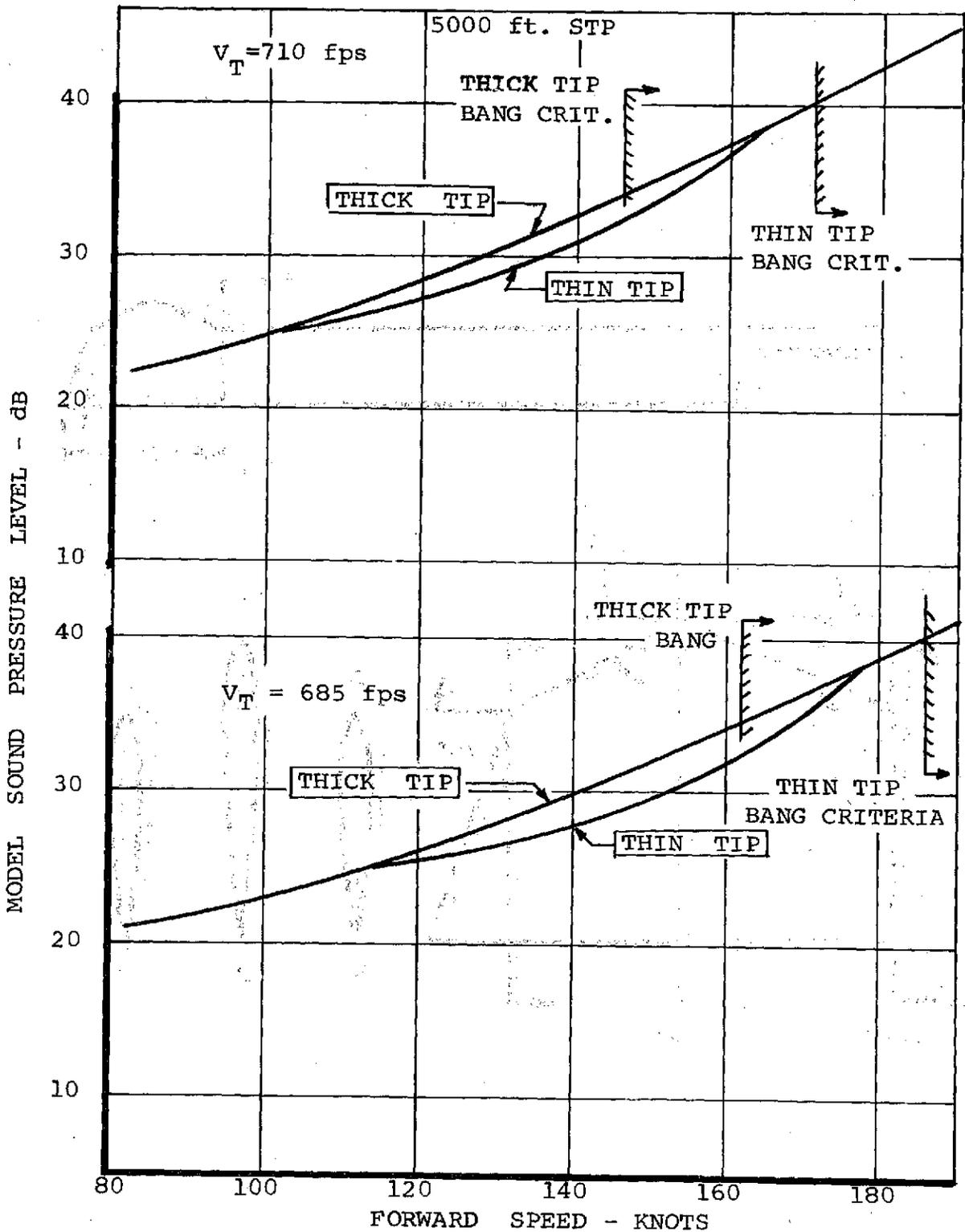


FIGURE 41 IMPROVEMENT OF BANG ENVELOPE BY THIN TIP

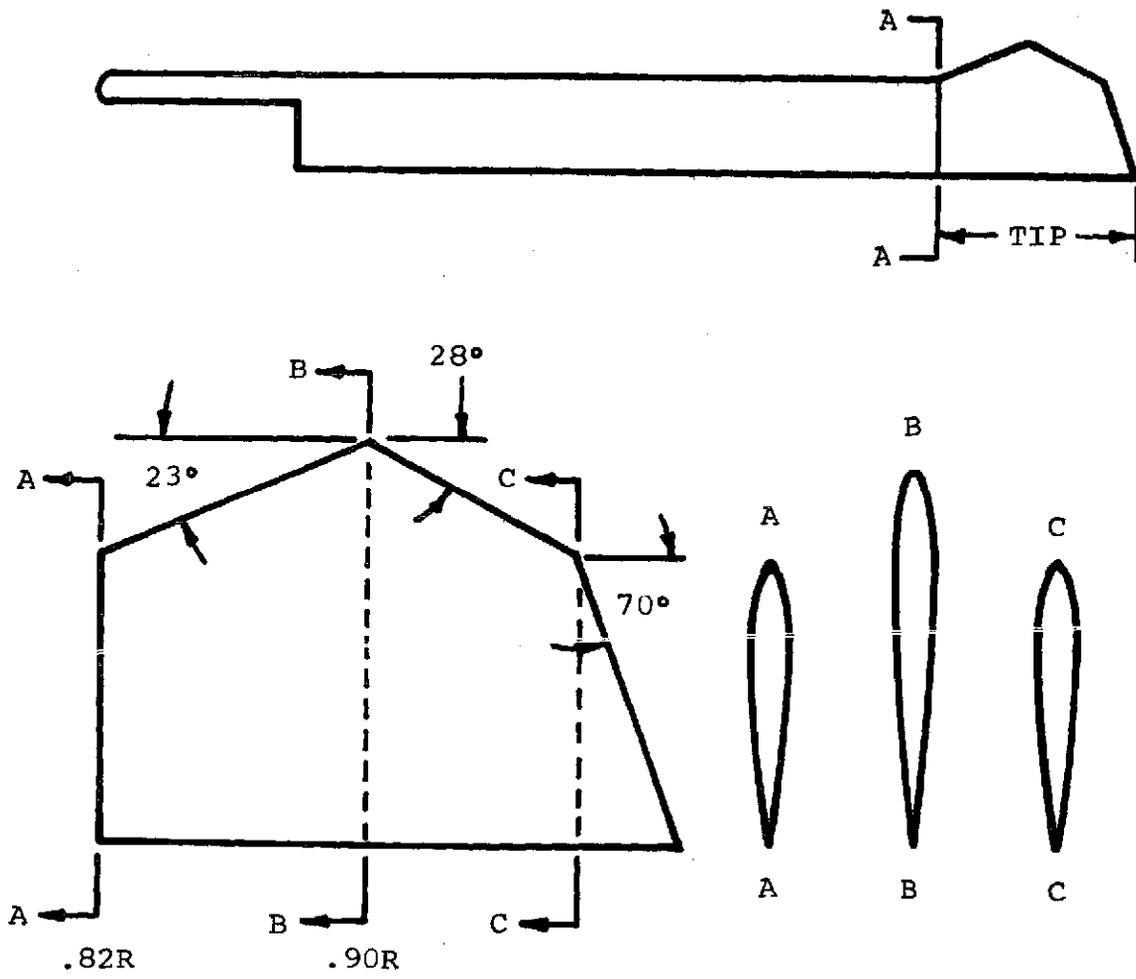


FIGURE 42 DOUBLE SWEEPED TIP CONCEPT

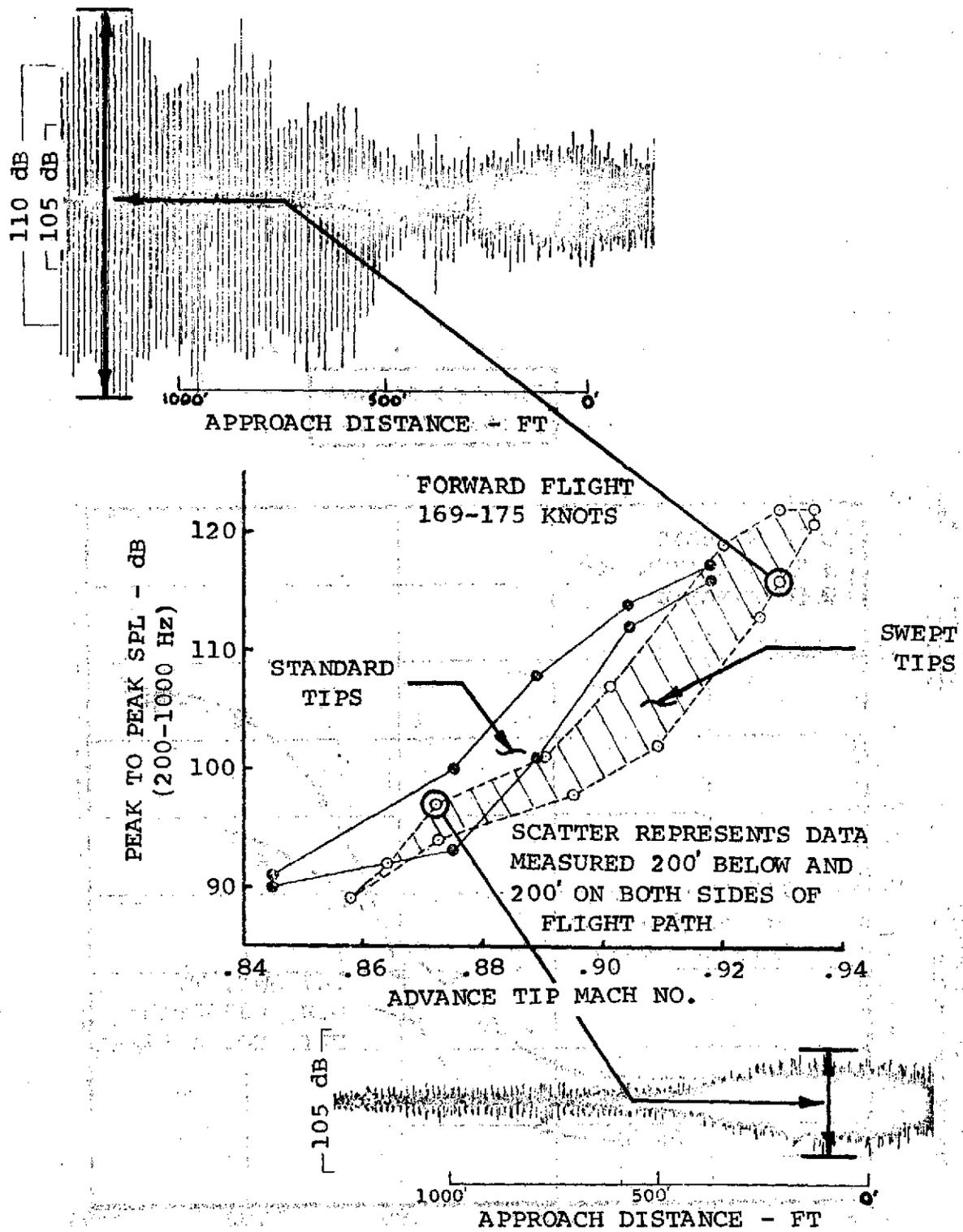


FIGURE 43. DOUBLE SWEPT TIP OBJECTIVE NOISE EVALUATION

FORWARD FLIGHT  
169-179 KTS

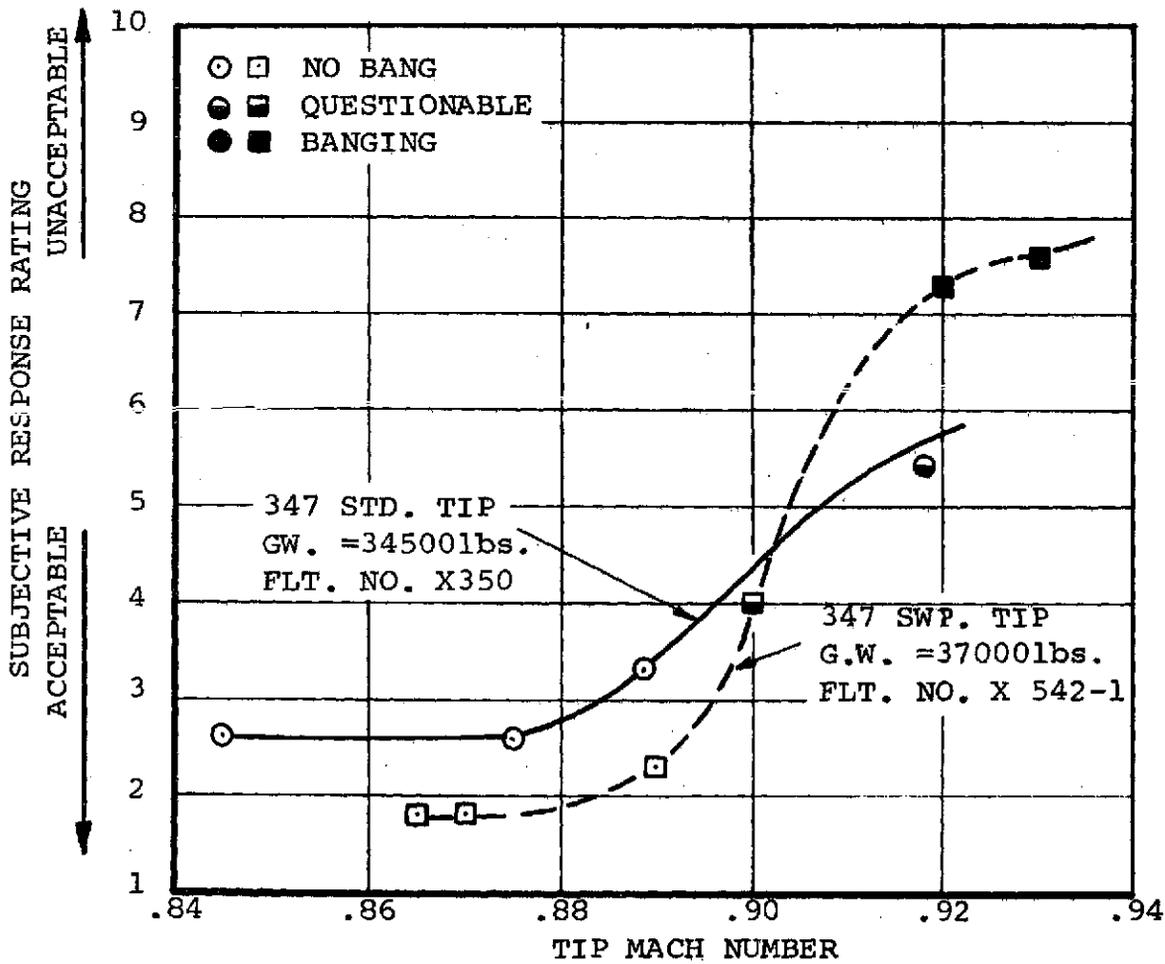


FIGURE 44 DOUBLE SWEPT TIP SUBJECTIVE NOISE EVALUATION

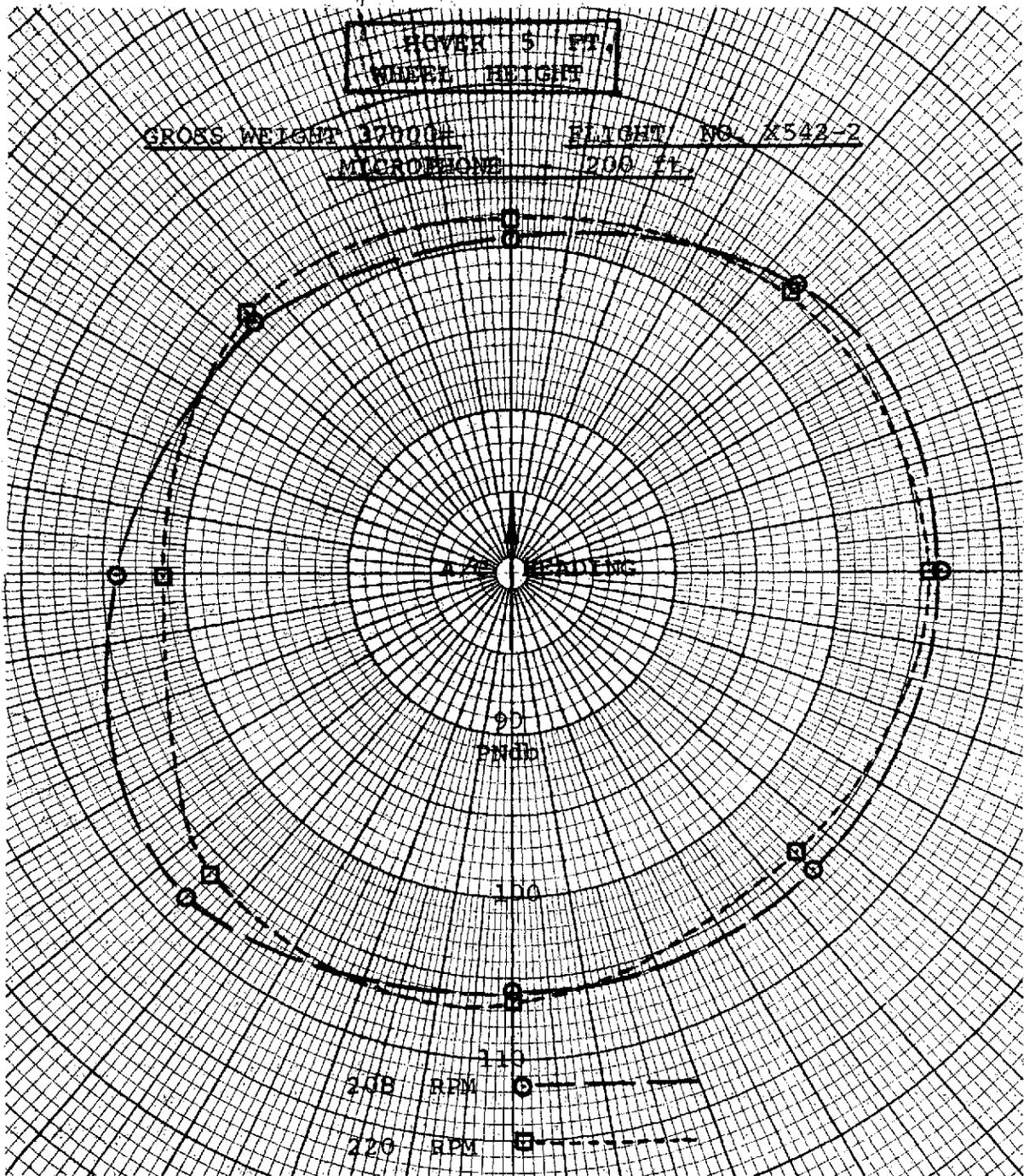


FIGURE 45 EFFECT OF TIP SPEED ON HOVER NOISE

ability of the lower rpm rotor. Unfortunately, reduction in rotor speed is accompanied by performance penalties, unless compensated by other features of rotor design, such as number of blades, chord, airfoil, etc.

The existing Model 347 helicopter has four blades per rotor. Increasing the number of blades per rotor to five, without decreasing rotor speed, could result in a reduction of two decibels for most rotational noise harmonics. This represents a perceived noise change of less than one PNdB. Going from four to six blades per rotor still does not change the perceived noise appreciably, but changes the decibel level by four. The other effect of increasing the number of blades on a rotor system is that it permits a reduction in rotor speed which has been discussed previously.

Changing the blade radius is a relatively ineffective way to change rotor noise. For the Model 347 helicopter rotor, a five foot radius increase in blade length indicates a negligible decrease in sound pressure level and perceived noise level in hover, and only up to two PNdB at 120 knots. This is whether the rotor lift is kept constant by simultaneous rpm changes or not. It is conceivable, however, that unequal blade radii on the same rotor, along with unequal angular blade spacing, could result in an optimum noise rotor flow environment. Test results from the latter concepts are expected soon from the NASA Langley Research Center.

Reducing the rotor speed not only affects the lift of the rotor, but also increases the torque. The increase in torque is accompanied by weight increases in the rotor and drive systems. In order to minimize the penalties associated with rotor noise reduction, the most promising approach lies in the development of blades using spanwise airfoil variation to optimize each portion of the blade both acoustically and aerodynamically. These concepts are already being applied to design blades for military helicopters, which maximize performance without undue noise penalties. An important contribution to civil helicopter development would be the design of similar concepts which minimize noise without undue performance penalties.

A promising rotor noise reduction concept investigated in this study is by means of rotor displacement harmonic control. A particular hardware approach under active investigation for vibration reduction is a pendulum absorber. Calculations

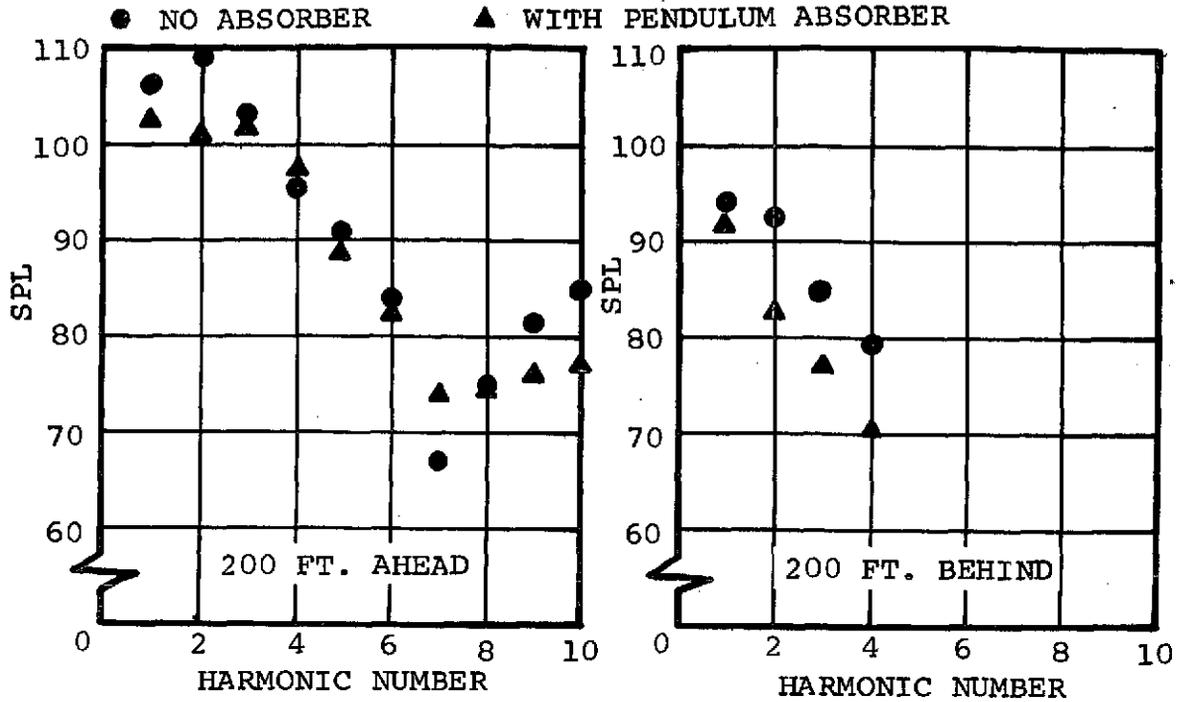
indicate that there may also be noise reduction benefits of appreciable magnitude, as illustrated in Figure 46. There is no guarantee, however, that an optimum vibration reducing absorber design may be best for noise reduction. Pending acquisition of full scale flight test data to verify the potential of this concept, it must be assumed that the technology is not available for direct application to a first generation short haul transport.

In contrast to the above concept, one which has been investigated by the Boeing Vertol Company and has as good, or better potential, is control of blade rigidity. This is especially true of torsional rigidity, or elasticity. A limited amount of airload data on rigid rotors is available, and the concept was investigated analytically on the rigid rotor of a BO-105 helicopter. Figure 47 indicates that in the range of the first seven noise harmonics on that rotor, the potential exists for substantial reduction of rotational noise.

One additional rotor noise source has received wide attention in the research and development area, and is referred here as rotor broad band noise. There is considerable controversy as to the importance, extent, and source of this noise. Some observers have postulated this noise source as a result of either rotor turbulent inflow, boundary layers, vortex, or tip noise. A general noise research program of investigation is indicated, since none of the mechanism have wide spread support as to the cause of rotor broad band noise. Since the importance of this noise source has not been clearly demonstrated, initial investigations should be confined to verifying the need for treatment.

Engine Noise: This particular noise source on the helicopter deserves a prime effort because these higher frequency generated noise levels strongly affect the values of Perceived Noise Level, and A-weighted noise levels which are expected to form the basis for both certification, and community noise criteria. Little work has apparently been done by the manufacturers of turboshaft engines, with regard to understanding the generation and propagation of powerplant noise. A broad investigation program consequently, involving microphones inside and outside the turbine is required. The T55-L-11 turbine used in the Model 347 helicopter has a particularly complex signature characterized by many discrete frequencies which are not identifiable by simple correlation with known

STEADY LEVEL FLIGHT  
160 KTAS



NOTE: ALL LOCATIONS 100 FT. BELOW ROTOR

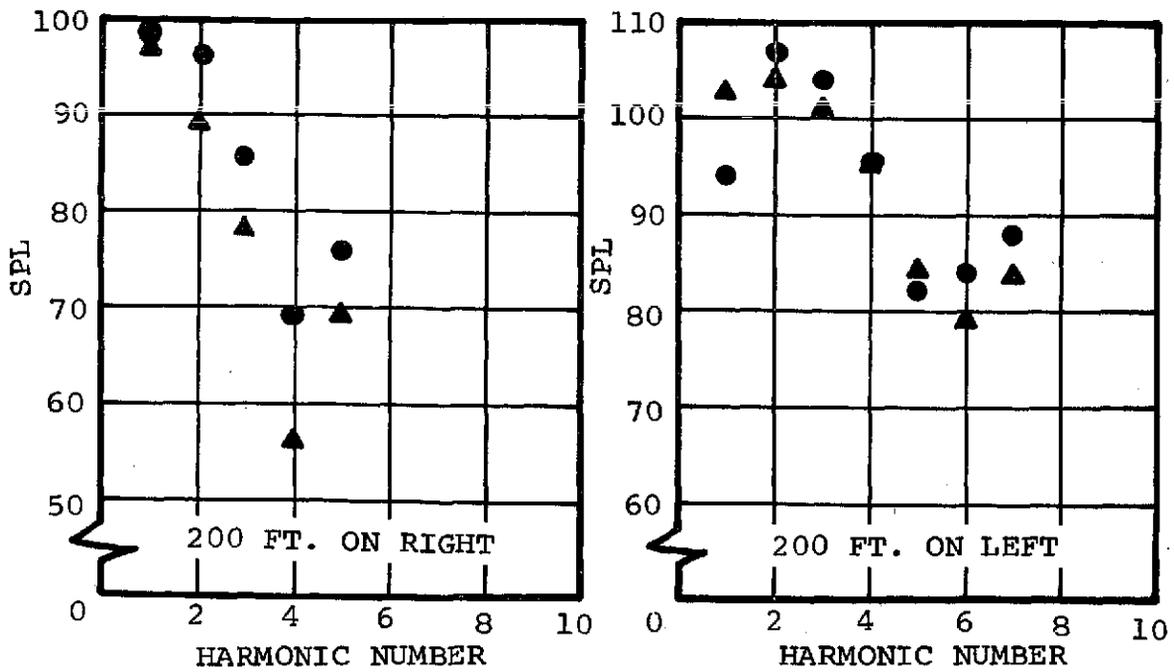


FIGURE 46 NOISE REDUCTION BY ROTOR HARMONIC CONTROL

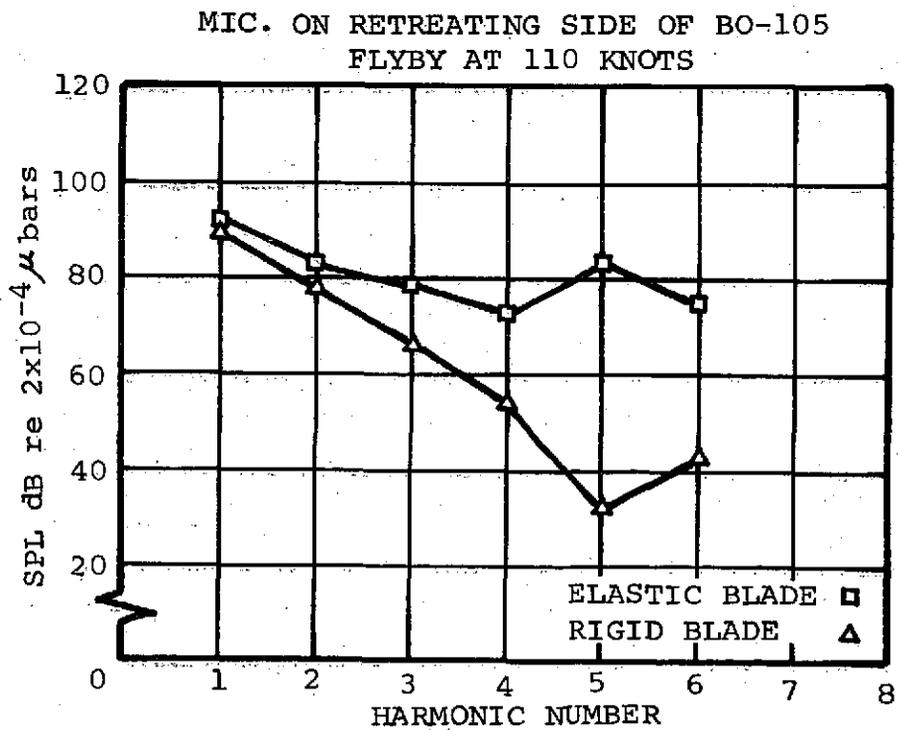
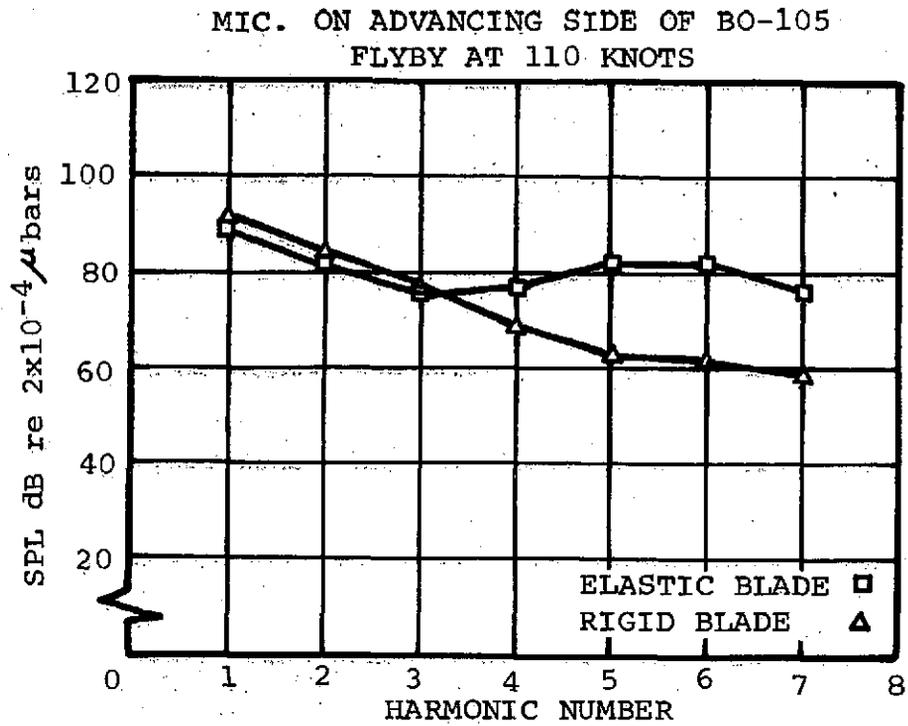


FIGURE 47 EFFECT OF BLADE TORSIONAL RIGIDITY ON NOISE

blade passage frequencies. A thorough measurement program is therefore required as a prerequisite to reduce powerplant noise of a Model 347 derivative. Inlet noise, consisting of discrete frequency compressor whine and broad band flow noise is the most prominent noise source, and fortunately, most amenable to treatment. Much of the groundwork required to suppress inlet noise can be adapted from Boeing's large, fixed-wing aircraft powerplant technology. Hardware candidates to control engine inlet noise include:

1. Tuned Inlet Lining
2. Rotor-Stator Spacing
3. Flow Velocity Shear Control
4. Flow Boundary Layer Thickness Control

Of these, the first item, tuned inlet lining, has progressed further technically. These linings are Helmholtz resonators, consisting of one or more layers of optimum sized honey-combed cells faced with a porous liner. When only one or two noise frequencies predominate, a relatively simple design can give up ten to fifteen decibels of noise reduction at the required frequencies. For a wider frequency range, several layers of acoustical treatment may be stacked, or arranged geometrically to attenuate inlet noise over a several octave band frequency range.

Engine exhaust noise is not expected to present any noise certification or community acceptance problems, due to the relatively low flow shearing velocities with the ambient air (350 to 400 feet per second). If, after suitable treatment of other predominant noise sources, it appears desirable to suppress exhaust noise to gain greater community acceptance of first, or larger, second generation helicopters, suitable exhaust nozzles can be designed, deflectors can alter noise directivity, or effective exhaust flow velocities may be lowered by ambient air mixing prior to egress from the engine. An engine noise source which is of greater concern than exhaust noise is called combustion noise, or core noise. The nature of this noise source is less well understood than inlet, or exhaust noise. It is amenable to control through either internal engine component redesign to optimize fuel injection, or by means of an increased noise transmission loss engine nacelle enclosure. The latter concept is fairly simple and should prove to be the most practical approach. Core noise also exits at the rear end of the engine and can be treated there by using absorptive lined exhaust ducts.

Other Noise Control Measures: In addition to source noise control techniques discussed in the preceding sections, several other helicopter noise control measures are available for consideration.

The helicopter's three-dimensional flight agility lends itself to noise exposure minimization on the ground by means of flight trajectory management, as was previously illustrated. Additional testing of this type could be conducted to further exploit the VTOL capability.

Hover time, if excessive, can play a major role in determining EPNL, and affecting community annoyance. The development of cockpit and terminal instrumentation, which will permit the helicopter to takeoff and land with minimum hover time is recommended.

#### Technology Status Assessment

The helicopter component noise reduction approaches discussed in the preceding section have been summarized in Table II to present an overview for an assessment of the status of required noise reduction technology for each concept. Each of the noise reduction methods have been assessed for its potential and direct applicability to a first-generation transport helicopter of the Model 347 type.

In considering whether the available technology is at hand to implement certain noise reduction methods at a reasonable risk, several candidate items were omitted from further consideration. Methods whose technical development required pursuance of a concept, or lacked proven applicability of a demonstrated practical approach, were removed.

For example, under rotational noise reduction methods, the concepts of harmonic control, elasticity, tips, and blade angular spacing all need a more solid technical foundation prior to being considered for production hardware application. They do, however, merit further investigation for potential long term applicability to second generation transport helicopters.

After elimination of insufficiently demonstrated concepts, there may still remain several approaches for the reduction of each noise component. These, however, may be redundant, in

Table II Helicopter Noise Reduction Approaches - Technology Status Assessment

Primary Noise Sources	Rotor											Engine															
	Hover Bang		High Tip Speed Bang	Rotational Noise						Broad-band Noise	Inlet		Core	Jet Exhaust													
Noise Classification	Rotor/Vortex	Rotor/Rotor									Discrete	Broad-band															
Noise Reduction Methods	Airfoil	Tips	Air Injection	Spoilers	Trim	Overlap	Tip	Airfoils/Vt	Number Of Blades	Airfoils/Vt	Planform	Harmonic Control	Spacing	Twist	Elasticity	Tips	Diameter	Turbulent Flow	Boundary Layer	Tip Noise	Vortex Noise	Tuned Liner	Compound Tuned Liner	Nacelle Treatment	Exhaust Absorber	Diffusers	Deflectors
Available Technology <sub>1</sub>	✓	✓			✓	✓	✓	✓	✓	✓				✓			✓	Program Required				✓	✓	✓	✓		
Recommended Approach <sub>2</sub>						✓	✓	✓	✓									Program Required To Define				Program Required To Define					

that application of one approach may obviate the need for the others. In this case, the most promising, and/or practical concepts, shown in line 2 of Table II are recommended.

#### CONCLUSIONS

It is possible, through the application of available technology, to modify an existing 50 passenger helicopter. (Boeing Vertol Model 347), so that it can meet civil helicopter noise requirements for the 1975-1980 time period while maintaining flight schedules permitting frequent operations in a daytime city environment.

Additional research and methodology development is required to provide similar capability for service to quiet suburban areas, or in cities at night.

Methods which can reliably forecast community response to helicopter rotor noise are not available.

The Boeing Vertol Company  
Philadelphia, Pa.  
May 3, 1974

APPENDIX A  
ROTOR NOISE ANNOYANCE

It is apparent from the discussion on V/STOL noise criteria in the early part of this report that the questions of certification and community acceptance are not bound by the same physical and psychological constraints. It has been shown, for example, that the units of time-weighted PNdB and dBA may be adequate as an objective measure of the physical sound magnitude of a helicopter for certification purposes, but a good measure of the relative or absolute subjective annoyance has yet to be defined. Such a definition is required for all helicopter sounds if aircraft designers, operators, and users are to reduce the risks associated with the potential for public annoyance and acceptability as represented by the acoustic signatures of today's large transport helicopters.

The far-field, external noise characteristics of large helicopters are dominated by low frequency energy whose temporal pattern consists of pulses at the rotor blade passage frequency, and this description is valid for both rotors of a tandem helicopter, and the main rotor of a single rotor helicopter. PNdB and dBA are good measures to use, objectively and subjectively, it has been shown, for those single rotor helicopter designs, or flight conditions in which the tail rotor noise is dominant. This is due to the higher number of blades and RPM on a typical tail rotor (as compared to the main rotor) resulting in blade passage frequencies whose period is more akin to those of conventional propeller noise. Historically, aircraft noise acceptability limits expressed in terms of PNdB were largely derived from propeller aircraft, and it is no surprise, therefore, that helicopter tail rotor noise can be judged in the same terms. The main rotor acoustic pulses of today's large transport helicopters are perceived as distinct separate events, unlike the smooth continuum of jet broadband noise, or the hum or drone of conventional propeller aircraft. It is therefore reasonable to expect that, because of both temporal and low frequency spectral characteristics, the units of PNdB leave something to be desired if applied to predict the acceptability, or annoyance, of large rotors.

Some of the foregoing has been conjectured and needs to be demonstrated. A small subjective test was therefore planned as part of this study. This test was to conduct a preliminary investigation to indicate whether a single existing objective measure, such as dBC or dBA (and, by implication, PNdB) could be used to accurately reflect large rotor noise annoyance or acceptability, and the results should therefore be treated as trend indications only.

## APPENDIX A

The test procedure consisted of asking a test subject to adjust the level of pulsed, low-frequency harmonic rotor noise until it was judged equal in annoyance to that evoked by a fixed level of shaped broad-band noise with smooth spectral characteristics over a large frequency range. This latter sound was chosen as a reference sound since its spectral and temporal characteristics were such that, when expressed in terms of a single weighted number using dBA or PNdB, a good correlation between level and annoyance could be expected. The test sounds to be judged consisted of synthesized harmonic rotor noise at a 15 HZ. fundamental frequency with three spectral characteristics:

1. A non-banging rotor whose noise harmonics dropped in level as a function of frequency so that a highly damped spectrum of thumping noise was obtained;
2. A normal rotor sound; and
3. A rotor sound with harmonic spectral characteristics typical of a banging or slapping rotor.

Figure A1 illustrates schematically the conduct of this comparative test. The test subject listened to the reference or test sounds through a pair of high-fidelity earphones whose low frequency characteristics had been verified to be superior to any available speaker system. After listening to the broad-band reference sound and judging its annoyance, the subject would switch over to the rotor sound, and adjust its level until he thought it equal in annoyance to the reference sound. The subject was permitted to switch back and forth between sounds as many times as he thought necessary to satisfy himself of the firmness of his decision. When a final decision was reached, the acoustic spectrum heard in the headphones was measured by means of a microphone imbedded in a solid wood mannequin head equipped with an identical pair of headphones.

A good objective measure of aircraft noise annoyance or acceptability should give nearly identical numerical values for equally annoying or equally acceptable sounds.

Figure A2 illustrates the results of this test in terms of several simple objective measures. Since the rotor sounds contained primarily low-frequency energy, it was anticipated that an overall sound pressure measurement such as dBC would give a good correlation with equal annoyance. The figure indicates, however, that when the higher harmonic levels of rotational noise were presented to the test subjects, the subjects compensated for the increase in total loudness or energy by turning the volume of the rotor sounds down. This

## APPENDIX A

is indicated by the drop in level shown for the banging rotor sound as compared to the other two test sounds at the top of Figure A2. In view of the predominance of high level, low frequency energy typical of a rotor spectrum as compared to the broad-band noise, there is also an upward shift in level when going from the broad-band noise to the three rotor noise spectra.

Figure A2 also indicates that using dBA units initially improves the correlation between broad-band noise and harmonic rotor noise, but this correlation deteriorates with an increase in rotor noise harmonic content, or degree of rotor bang. Therefore, dBA, and by implication PNdB, is not the sought after objective measurement unit. This ideal unit, valid for rotor sounds, aircraft sounds and in fact, all types of acoustic noise would yield an identical numerical value for all sounds, but is still to be defined.

Since the results of this preliminary investigation appear to support the hypothesis that dBA (PNdB), or dBC does not adequately reflect subjective evaluations of rotor noise a formal, large-scale psycho-acoustic test program should be conducted. This program should encompass a larger number of rotor noise spectra and repetition rates and be conducted using a valid test population.

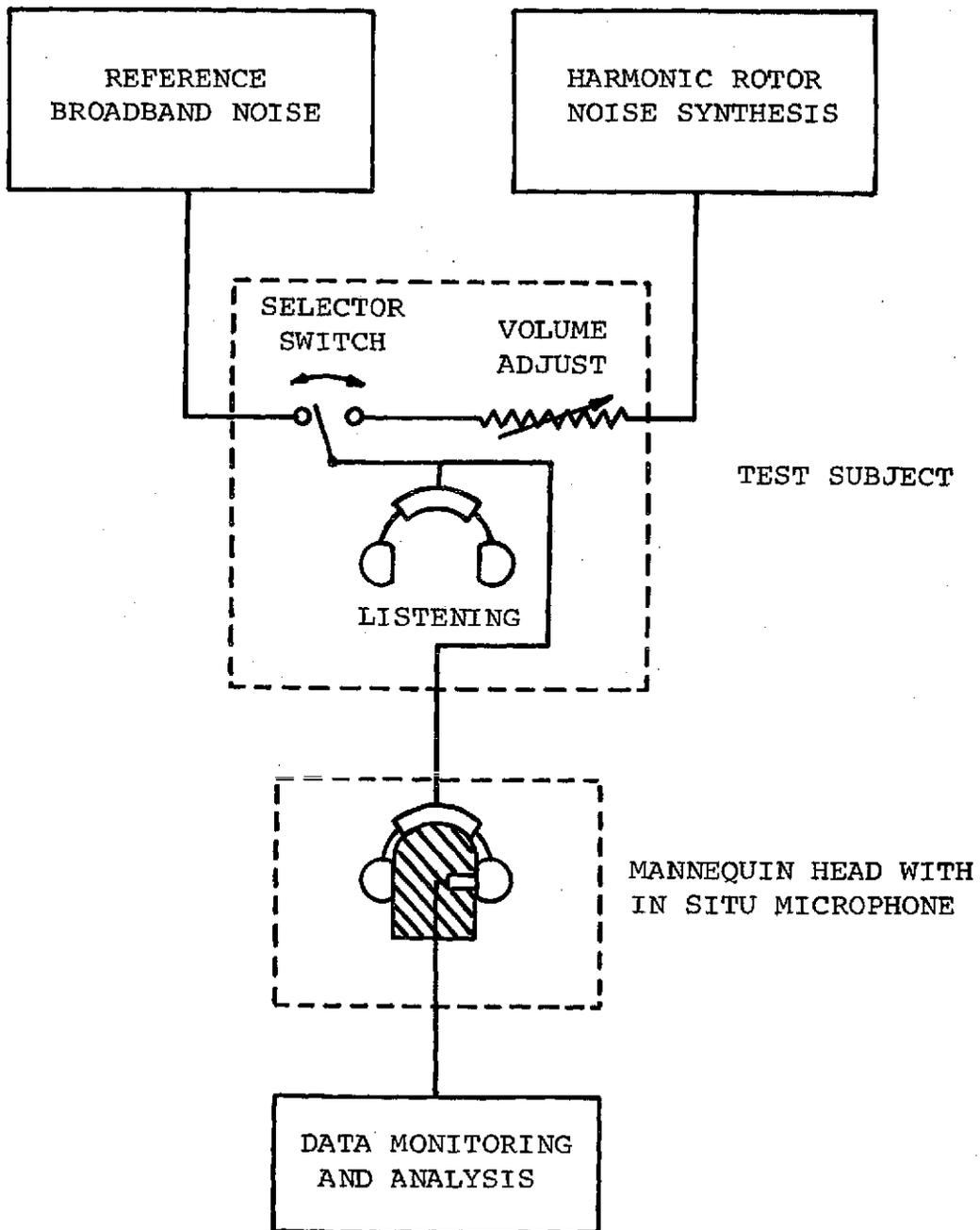
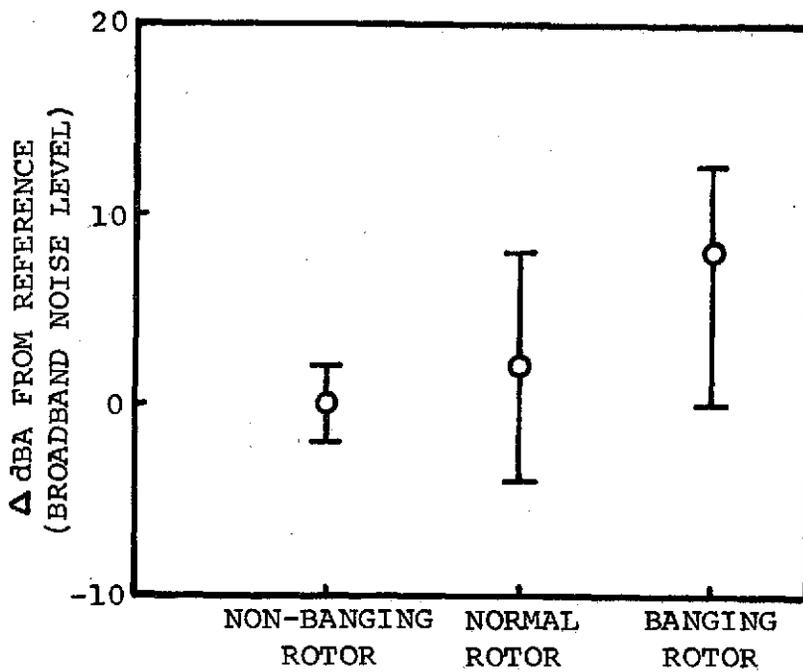
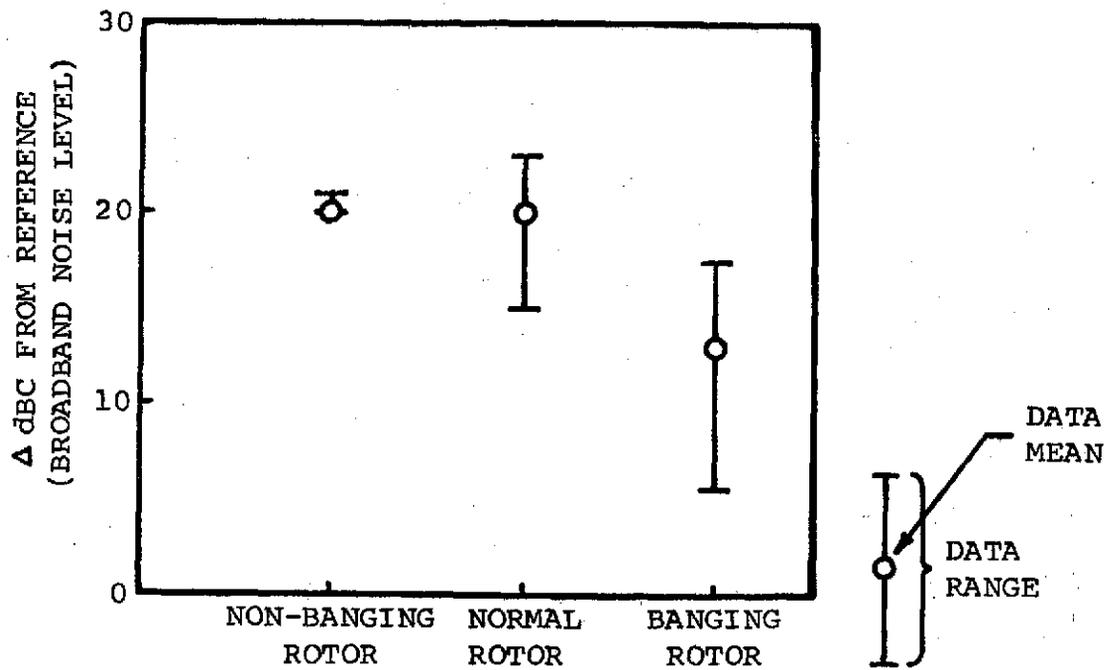


FIGURE A1. PRESENTATION OF SYNTHESIZED ROTOR NOISE TO TEST SUBJECTS



BLADE PASSAGE PERIOD = 15 Hz

5 TEST SUBJECTS

FIGURE A2. RELATIVE LEVELS OF THREE TYPES OF ROTOR SOUNDS JUDGED EQUALLY ANNOYING TO A BROADBAND NOISE

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